Newtonian Cosmology with Renormalized Zero-Point Radiation

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It is shown that the infinite energy density of zero-point radiation can be renormalized to a finite value, $K\rho_o c^2$, where $K\rho_o$ is the inertial mass density corresponding to gravitational mass density ρ_o, by inclusion of gravitational self-potential energy, provided that $4\pi G\rho_o R^2 = 3Kc^2$, which is the condition that $K\rho_o c^2$ closes the universe at radius R. When material mass m^* is renormalized in the same way the result is $m(r) = -(m^*/2)(1 - r^2/R^2)$. Negative mass m(r) interacting gravitationally with positive ρ_o is accelerated outwards subject to $K\gamma^2 m(r) =$ constant, where $\gamma = (1-\beta^2)^{-1/2}$, so that matter of the universe expands with velocity field $\beta = r/R$. The Hubble redshift can therefore be given a Doppler interpretation.

A velocity field $\beta = r/R$ and a Doppler interpretation of Hubble's effect are obtained in de Sitter cosmology, but only as one of several equally valid interpretations depending on reference system. For Robertson coordinates the Hubble redshift emerges in exponential form and receives a "tired-light" interpretation in a stationary universe. The same must be expected for extended Newtonian cosmology.

Following previous work, Planck radiation oscillators are quantized gravitationally as eigenstates of a fundamental oscillator of minute constant energy $\hbar\omega_o$, where $\omega_o = c/R$. Quanta $\hbar\omega_o$ (gravitons) can be scattered from the ω-radiation field to the ω'-radiation field, redshifting one and blueshifting the other so that it is possible for an arbitrary radiation spectrum to attain the equilibrium blackbody spectrum without interacting with matter. The redshift $d\omega$ over the path $d\ell$ in a medium with radiant energy density is $d\omega/\omega = -AU d\ell$, where A is a constant with theoretical value $A = 6.4\times10^{-21}$ erg^{-1} cm^2. When $U = K\rho_o c^2$ the redshift law reduces to Hubble's law $d\omega/\omega = -d\ell/R$, which integrates to the exponential form obtained in de Sitter cosmology with Robertson coordinates.

When U is the radiant energy density in a quasar there arise local (anomalous) redshifts exceeding the Hubble redshift. For a quasar at distance r the Hubble redshift varies as r, but the value of U varies as r^2. It is found that the local redshift dominates the Hubble redshift for $r > r^*$, where $r^* = 0.014R$ is estimated from observed quasar fluxes and dimensions. The anomalous distribution of high-redshift quasars is explained. A possibility for testing the redshift law in the laboratory is explored briefly.

1. Introduction

Elsewhere it has been argued that the adoption of a flat space-time is a permissible option if one introduces co-varying unit fields for the dimensional quantities (Browne 1977). In this paper, Newtonian cosmology is extended in a manner which yields the same effects as are obtained for the de Sitter cosmology in Einstein's theory. In particular, the emergence of the Hubble redshift in de Sitter cosmology as a Doppler-*cum*-gravitational effect for de Sitter co-ordinates and as a "tired light" effect for Robertson coordinates can be matched in extended Newtonian cosmology.

Particular attention is given to the explanation of the exponential redshift formula in terms of graviton scattering. The effect is attributed to scattering of gravitons from the ω-radiation field to the medium radiation field with energy density *U*. When *U* is zero-point radiation, renormalized by inclusion of self-gravitational potential energy to a finite value which closes the universe at radius *R*, Hubble's law is obtained. When *U* is the local radiant energy density in a quasar, there results a local (anomalous) redshift which can exceed the Hubble redshift. It is concluded that the redshifts of sources more distant than about 0.014*R* are not Hubble effect.

2. Renormalized Zero-point Radiation

It is argued that zero-point radiation (vacuum fluctuations), with energy density renormalized to a finite energy density $K\rho_o c^2$ by inclusion of potential energy density due to self-gravitational interaction, closes the universe at finite radius *R*. Vacuum fluctuations are often regarded as a purely quantum mechanical effect without classical analogue. However, papers extending over a number of years (Weiskopf 1939, Welton 1948, Marshall 1963, Power 1966, de la Pena-Auerback and Garcia-Colin 1968, Boyer 1978) have shown that it is possible to regard vacuum fluctuations as classical electron motion driven by zero-point radiation. In taking this viewpoint remarkable insights for the meaning of quantum mechanics are achieved.

Classically, zero-point radiation has energy $\hbar\omega/2$ per standing wave mode of frequency ω, of which there are $\omega^2 \mathrm{d}\omega/\pi^2 c^3$ in unit volume in frequency range $\omega \to \omega + \mathrm{d}\omega$. Thus the energy density of zero-point radiation in $\omega \to \omega + \mathrm{d}\omega$ is $U_\omega \mathrm{d}\omega$, and over all frequencies is U_o, where

$$U_o = \int U_\omega \mathrm{d}\omega = \int \frac{\hbar\omega^3}{2\pi^2 c^3}\mathrm{d}\omega = \frac{\hbar\omega^4}{8\pi^2 c^3} \tag{1}$$

Adding the zero-point radiation to blackbody radiation for temperature *T*, we obtain (see Marshall 1963)

$$U_\omega(T) = U_\omega \frac{1+x}{1-x} \tag{2}$$

where $x = \exp(-\hbar\omega/kT)$, and where U_ω is given by (1). Zero-point radiant energy is not measurable because the most sensitive detector is already in equilibrium with zero-point radiation. Only finite temperature is detectable.

The mass density of radiation must take into account the work done by radiation pressure when a cavity containing blackbody radiation expands at constant temperature. Because the energy density of the radiation *u* remains constant if temperature is constant, the increase in volume $\mathrm{d}V$ adds $U\mathrm{d}V$ to the energy, and the work done, $p\mathrm{d}V$, adds a further $U\mathrm{d}V/3$ to the energy. The gravitational mass of the zero-point radiation of energy density *U* is, therefore, $4U/3Kc^2$ (see Tolman 1934).

The Newtonian potential for a universe of radius R containing uniform gravitational mass density ρ_o is given by

$$\phi(r) = -2\pi G\rho_o R^2 \frac{1-r^2}{3R^2} \tag{3}$$

If $K\rho_o c^2$ is the energy density of zero-point radiation renormalized to a finite value by inclusion of its gravitational potential energy density in the universe with potential (3), we must have

$$U + \frac{4U}{3Kc^2}\frac{\phi(0)}{2} = U\frac{1-4\pi G\rho_o R^2}{3Kc^2} = K\rho_o c^2 \tag{4}$$

Since $U \to \infty$ as $\omega \to \infty$, (4) can be satisfied only if

$$4\pi G\rho_o R^2 = 3Kc^2 \tag{5}$$

One notes that (5) and (3) imply that

$$m\phi(R) + Kmc^2 = 0 \tag{6}$$

which expresses the fact that the total energy of any mass *m* vanishes at $r = R$.

We must renormalize the electromagnetic mass m^* of matter as well as of radiation. Then the gravitational potential of bare mass m^* in the universe potential field (3) is renormalized to *m*(*r*), where

$$\begin{aligned} Km(r)c^2 &= Km^*c^2 + m^*\phi(r) = m^*[\phi(r) - \phi(R)] \\ &= -\left(1 - \frac{r^2}{R^2}\right)\frac{Km^*c^2}{2} \end{aligned} \tag{7}$$

the final expression being obtained by use of (3) and (5). Hence

$$m(r) = -\left(1 - \frac{r^2}{R^2}\right)\frac{m^*}{2} \tag{8}$$

Thus, renormalized material mass is negative, whereas renormalized zero-point radiation has positive mass density. The interaction of *m*(*r*) with universe gravitational mass therefore reverses the motion of *m*(*r*) so that it falls outwards. Because *m*(*r*) decreases as *r* increases, kinetic energy must increase in order that a particle of mass *m* should maintain constant energy. The unit of energy also varies with *r* because space-time has been flattened. A constant of the motion is

$$K\gamma^2 m(r)c^2 = -\frac{1}{2}Km^*c^2\frac{1-{r^2}/{R^2}}{1-\beta^2} = \text{constant} \tag{9}$$

One γ factor in (9) provides kinetic energy and the other corrects for measures being reduced by use of an increased unit of energy. It follows that

$$\beta = \frac{v}{c} = \frac{r}{R} \tag{10}$$

The velocity field (10) describes universe expansion in accordance with the Doppler interpretation of the Hubble effect. The expanding universe can therefore be obtained from Newtonian cosmology. The same velocity field follows from de Sitter cosmology, using de Sitter coordinates.

3. Gravitational Electron Radius

For reasons which will become apparent in section 5, it is necessary to divert the discussion to a topic which may seem, at the moment, to be unrelated to the previous discussion, namely the gravitational radius of the electron. Consider an electron with bare charge q and renormalized mass $m(r)$. The imaginary quantity $i\overline{m}$, where $\overline{m} = G^{½}m$, may be treated as gravitational charge. Then we expect that the energy density $E^2/8p$ in the unified complex field $E = E' + iE''$ will provide the gravitational mass density $E^2/8pKc^2$, which is the source of the gravitational field. In fact, it provides the source for both the gravitational and electromagnetic fields, as follows. The Poisson equation $\nabla \cdot E = 4pr$, for complex E and complex r $(= E^2/8pKc^2)$ is

$$r^{-2}\mathrm{d}\left(r^2 E\right) = iaE^2 \tag{11}$$

where $a = G^{½}/2Kc^2$. Let $Q = r^2 E$, so that (10) becomes

$$\frac{\mathrm{d}Q}{\mathrm{d}R} = \frac{iaQ^2}{r^2}$$

which integrates to

$$Q^{-1} - Q_o^{-1} = \frac{ia}{r} \tag{13}$$

where Q_o is an integration constant. As $r \to \infty$, we see that $Q \to Q_o$, which allows us to make the identification $Q_o = q + i\overline{m}$. Substituting this value for Q_o, and noting that $Q = Er^2$, we obtain a solution with real and imaginary parts

$$E' \cong \frac{q}{r^2 + a^2} \tag{14a}$$

$$E'' \cong m\frac{1 - b/2r}{r^2 + a^2} \tag{14b}$$

where

$$a = \frac{qG^{½}}{2Kc^2}, \qquad b = \frac{qa}{\overline{m}} \tag{15}$$

We choose q to be the bare charge $(\hbar c)^{½}$ rather than the Coulomb charge e. Then $q^2 = \hbar c = 137e^2$, and

$$a = (2K)^{-1}\left(\frac{Gh}{c^3}\right)^{½} = 0.8 \times 10^{-33}\ \text{cm} \tag{16a}$$

$$b = \frac{\hbar}{Kmc} = 3.86 \times 10^{-11}\ \text{cm} \tag{16b}$$

The constant a is the gravitational radius of the electron, and b is the Compton wavelength of the electron. If one puts $q = e$, then a is reduced by a factor $(1/137)^{½}$ and b is reduced by a factor 1/137, becoming the classical electron radius e^2/Kmc^2. The approximations in (14) are $\overline{m} << q$ and $Gm/Kc^2 << a$, both well satisfied.

Note that the gravitational field of the electron varies as r^{-3} when r is in the range between b and a; specifically, for $b >> r >> a$, (14b) is $E'' \cong qa/r^3$. For $r = a$, we obtain from (14),

$$E' \cong \frac{q}{2a^2} \qquad E'' \cong -\frac{q}{2a^2} \tag{17}$$

Thus, the gravitational and electromagnetic field strengths of the electron are equal at $r = a$. Also, the real and imaginary charges of the electron become equal at $r = a$; that is, $m(a) = q$. The radius a is also the Schwarzschild radius for bare mass , the Schwarzschild radius for renormalized mass being $Gm/Kc^2 = 6.75 \times 10^{-56}$ cm.

How to generalize the above to a complete unified field theory was discussed previously (Browne 1977).

4. De Sitter Cosmology

De Sitter cosmology offers the closest parallel to our extended Newtonian cosmology, but must be assumed not to be empty. We assume that zero-point radiation is present in constant density $Kr_o c^2$, the "cosmological fluid". The following results are available from Tolman (1934). With the choice of de Sitter coordinates (r, t), the radial geodesics provide velocity field $v/c(r) = r/R$, where $c(r) = \left(1 - r^2/R^2\right)^{-½}$, and the Hubble redshift emerges as $w_2/w_1 = 1 - r/R$, which is a product of a relativistic Doppler effect $g(1 - b)$ and a gravitational redshift g^{-1}, where $g = \left(1 - b^2\right)^{-½}$. However, with respect to Robertson coordinates $(\bar{r}, \bar{t})$, the universe fluid is at rest and the Hubble redshift is a consequence of dependence of light velocity $c(\bar{t})$ on epoch $\bar{t}$. Specifically, $w_2/w_1 = \exp(-\ell/R)$, where $\ell = c(\bar{t}_2 - \bar{t}_1)$. Because the Robertson form of metric is invariant under a transformation to a new time origin, specifically $\bar{t}' = \bar{t} - \Delta\bar{t}_o$ and $r' = r\exp(c\Delta\bar{t}_o/R)$, it is possible to maintain constant epoch during light propagation by successive infinitesimal changes of time origin. Then the exponential redshift formula is interpreted as frequency decay. We expect the same for our extended Newtonian cosmology.

In de Sitter cosmology the interpretation of the Hubble redshift changes radically from reference system to reference system, although the effect is always present. All interpretations are equally valid, because reference systems are arbitrary when equations are generally covariant. Physically, this means that the equations describe a perfectly isolated system, so that there is no external reference for velocity. Expansion of the universe with respect to reference system (r, t) cannot be distinguished from contraction of reference system (r, t) with respect to the universe (Browne 1979). In this light, the conventional "big bang" cosmology looks quite naïve.

5. Redshifts due to Graviton Scattering

Having concluded that zero-point radiation with gravitationally renormalized energy closes the universe at radius R, a "tired light" interpretation for the Hubble redshift proposed many years ago (Browne 1962) is now reappraised. The proposal made previously was that Planck's radiation oscillators should be quantized gravitationally as eigenstates of a fundamental simple harmonic oscillator of minute energy $\hbar w_o$, where $w_o = H = R/c$, H being the Hubble constant. The wavelength for w equals the circumference of the universe, $2pR$. For a radiation oscillator of frequency w we have

$$w = \left(n + \tfrac{1}{2}\right)\hbar w_o = \left(n + \tfrac{1}{2}\right)\frac{c}{R} \tag{18}$$

where n is a very large integer. The selection rules for a harmonic oscillator $\Delta n = \pm 1$ constrain the w-radiation to lose or gain gravitons one at a time, which implies gradual change of frequency. Introducing energy x by $\hbar w_o = 2x$,

$$x\frac{R}{c} = \frac{\hbar}{2} \tag{19}$$

which has the form of an uncertainty relation. Energy x becomes an uncertainty in all energies arising because times exceeding the Hubble age R/c are not available for measurement. Although (18) implies that the spectrum of electromagnetic radiation is always discrete, this discreteness is so fine that it cannot be observed.

Graviton scattering permits radiation trapped in a cavity with perfectly reflecting walls to attain the equilibrium blackbody spectrum in the absence of matter, which is not possible by recognized interactions. The universe may be treated as such a cavity. As w-radiation from a distant source propagates through a medium with radiant energy density U, there occurs scattering of gravitons from the w-radiation field to the radiation field of the medium, leading to a gradual redshifting of the w-radiation. This may be the first step in the continual creation of matter from radiation which would balance the annihilation of matter into radiation in stars in a steady-state universe (Browne 1962).

A medium with radiant energy density U has graviton density $N = U/\hbar w_o$. The probability for scattering from the w-radiation field n to the medium field N is proportional to nN. For cross section s the rate is

$$\frac{\mathrm{d}n}{\mathrm{d}t} = -nscN = -\frac{-nscU}{\hbar w_o} \tag{20}$$

In time dt, distance propagated is $\mathrm{d}\ell = c\mathrm{d}t$. Then, noting that $\mathrm{d}n/n \cong \mathrm{d}w/w$,

$$\frac{\mathrm{d}w}{w} = -\frac{sR}{\hbar c}U\mathrm{d}\ell \tag{21}$$

The cross section s must be of the order of a, where a is the gravitational radius of the electron given by (16a) (Browne 1976b). In analogy to the Thomson cross section for scattering of radiation by a free electron, we choose

$$s = \frac{16pa^2}{3} = \frac{4pG\hbar}{3K^2c^3} = 1.07 \times 10^{-66}\ \mathrm{cm}^2$$

Then (21) yields

$$\begin{aligned} \frac{\mathrm{d}w}{w} &= -AU\mathrm{d}\ell \\ A &= \frac{4pGR^2}{3K^2c^4} = 6.4 \times 10^{-21}\ \mathrm{erg}^{-1}\ \mathrm{cm}^2 \end{aligned} \tag{23}$$

the value for A being based on $H = 50\ \mathrm{kms}^{-1}\ \mathrm{Mpc}^{-1}$ ($R = 1.85 \times 10^{28}$ cm).

As a special case we seek to obtain from (23) the Hubble redshift, taking the radiation density of intergalactic space to be that of renormalized zero-point radiation. Then, from (4) and (5)

$$U = Kr_o c^2 = \frac{3K^2c^4}{4pGR^2} \tag{24}$$

Substitution of (20) into (18) yields

$$\frac{\mathrm{d}w}{w} = \frac{-\mathrm{d}\ell}{R}, \qquad w_2 = w_1 \exp\left(\frac{-\ell}{R}\right) \tag{25}$$

which is the exponential form of Hubble's law, w_1 being the emitted frequency and w_2 being the received frequency.

The question of momentum transfer during graviton scattering remains to be considered. Transfer of a graviton from an w-photon to an w'-photon which propagates transversely to the direction of the w-photon has the consequence that the w'-photon gains momentum $\hbar w_o/c$, which must be balanced by giving the w-photon equal and opposite momentum $\hbar w_o/c$ in the transverse direction. The w-photon will therefore be deflected through a very small angle w_o/w.

When radiation of the medium is isotropic there is equal probability of deflection to the right or to the left. The total number of interactions required for redshift Δw is $\Delta w/w_o$, and the excess deflections in one direction are $(\Delta w/w_o)^{1/2}$, giving angular spread

$$\langle dq \rangle = \left(\frac{\Delta w}{w_o}\right)^{1/2} \frac{w_o}{w} = \frac{(w_o \Delta w)^{1/2}}{w} \qquad (26)$$

Because w_o is so small, $\langle dq \rangle$ is undetectable.

However, when the radiation of the medium is unidirectional and transverse to the w-radiation beam, the deflection of the w-beam becomes measurable. If the medium has radiant energy density $U_\perp$ which propagates transversely to the w-radiation, the w radiation will suffer a deflection

$$\Delta q = \frac{\Delta w}{w} = A \int U_\perp \mathrm{d}\ell \qquad (27)$$

6. Observational Tests

A considerable time ago Finlay-Freundlich (1952) proposed a redshift law of the form (23) on the basis of empirical evidence for unexplained astrophysical redshifts in hot stars, and he applied the relation also to the Hubble redshift using for U the energy density of averaged starlight, which is comparable to the energy density of the 2.735° K cosmic blackbody radiation (4.23×10^{-13} erg cm^{-3}), not then discovered. The energy density of zero-point radiation which closes the universe at $R = 1.85 \times 10^{28}$ cm is 8.5×10^{-9} erg cm^{-3}, some four orders of magnitude greater than the 2.7° K radiation. Thus, the value of A obtained empirically by Finlay-Freundlich was some six orders of magnitude greater than the theoretical value (23).

Finlay-Freundlich did not have the benefit of knowing about the large redshifts later discovered for quasars. The radiant energy density U in a quasar of radius ℓ at a distance hR as estimated from the flux density F received at Earth is given by

$$Uc \cong F\left(\frac{hR}{\ell}\right)^2 \qquad (28)$$

The exponential redshift formula has exponent $AU\ell$ for redshift due to local radiation and exponent h for the Hubble redshift due to zero-point radiation. The exponents become equal when $h = h^*$, where

$$h^* = \frac{\ell c}{AFR^2} = 1.4 \times 10^{-26} \frac{\ell}{F} \qquad (29)$$

and where ℓ is in cm and F in erg s^{-1} cm^{-2}, and $R = 1.85 \times 10^{28}$ cm (for $H = 50$ km s^{-1} Mpc^{-1}). For ℓ we choose a characteristic dimension of the source, obtained as the light transit time for the shortest time scales on which F fluctuates at any wavelength. At X-ray wavelengths, variability time scales suggest $\ell \cong 10^{13}$ cm, and in one case $\ell \cong 10^{12}$ cm (Kuneida *et al.* 1990). Typically, $F \cong 10^{-11}$ erg s^{-1} cm^{-2}. Then (29) yields $h^* = 0.014$. Sources more distant than $0.014R$ will exhibit anomalous redshifts exceeding their Hubble redshifts. This results explains why the distribution in space of high-redshift quasars is anomalous.

Other evidence for anomalous redshifts has been accumulating for some years (Arp 1987). Often a quasar is associated with a galaxy having considerably smaller redshift, the association sometimes being a thin filament joining the quasar to the galaxy. On the basis of a model for such sources proposed previously (Browne 1993), the bright quasar is seen where the line of sight becomes tangent to a magnetic vortex tube (MVT), and the faint filament where the MVT is transverse to the line of sight.

Another type of observational test concerns the deflection of a beam of light by interaction with a transverse beam of light. Let light from a point source pass close to the limb of a star of radius R_S and temperature T. Let r be the distance from the centre of the star to a point on the light ray and let y be the perpendicular distance to the ray. Then the surface flux density is sT^4, where s is Stefan's constant, and the transverse energy density is

$$U_\perp = \frac{sT^4 R_S^2 y}{r^3 c} \qquad (30)$$

and (27) yields (noting $r^2 = \ell^2 + y^2$)

$$\Delta q = \frac{2AR_S^2 sT^4}{cy} \qquad (31)$$

To take the extreme case of a supergiant star for which $T \cong 40{,}000°$ K and $R \cong 100$ solar radii, (31) yields $dq = 44.5(R/y)$ arcsec, which is detectable.

In the case of crossing quasar beams, the deflection would be much larger, but of course the source of the transverse quasar beam would not be seen by us due to beaming of the quasar emission.

The possibility of a laboratory test for the redshift law (23) should be considered†. One requires very high radiant energy densities over paths as large as possible under conditions in which very small values of $\Delta w/w$ can be measured. Lasers provide high values for U, but we must have continuous output in order to avail ourselves of techniques which would measure very small values of $\Delta w/w$. The measurement time must, at the very least, exceed $2p/\Delta w$. The highest continuous power densities (power per unit area of beam, P/S) are achieved within laser cavities which are unstable resonators. Then the multiple round trip propagation path in the cavity progressively concentrates the beam toward the axis, and in the limit would yield infinite power density on the axis if the mirrors had 100% reflectivity. One thinks of a CO_2 laser operating at wavelength 10.6mm with large diameter (perhaps 10 cm) reflecting metal mirrors. Now let a small hole of radius perhaps 1 mm be drilled at the centre of

† I am indebted to R. Keys for drawing my attention to such a possibility.

each mirror. This will concentrate the escaping high-power 10.6 μm flux to a beam of cross sectional area $S \cong 3 \times 10^{-2}$ cm^2. At the same time, it will be possible to pass the beam from a low-power He-Ne laser axially through the cavity of the high-power laser, enabling a substantial interaction path length ℓ to be achieved. Heterodyne detection techniques allow the measurement of very small changes of frequency of single mode He-Ne laser emission, perhaps as small as $\Delta\omega/2\pi \cong 10$ Hz, corresponding to $\Delta\omega/\omega \cong 2 \times 10^{-14}$.

From (23), the power P of the high-power laser must satisfy

$$\frac{\Delta\omega}{\omega} = A\left(\frac{P}{cS}\right)\ell \cong 2 \times 10^{-31}\,\frac{P\ell}{S} \qquad (32)$$

where ℓ is the total interaction path length. For the values $\Delta\omega/\omega = 2 \times 10^{-14}$, $S = 3 \times 10^{-2}$ cm^2 and $\ell = 100$ m over a path folded by multiple reflections, equation (31) predicts that P = 30 kW would be required. This power is achievable from continuous wave CO_2 lasers, although not easily.

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