Remarks on the “New Redshift Interpretation”

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Abstract

In a recent article in Modern Physics Letters A, Gentry proposed a new static cosmological model that seeks to explain the Hubble relation as a combination of gravitational and Doppler red shifts. We show that Gentry’s model, although supposedly based on general relativity, is inconsistent with the Einstein field equations; that it requires delicate fine tuning of initial conditions; that it is highly unstable, both gravitationally and thermodynamically; and that its predictions disagree clearly with observation.
In a recent article in *Modern Physics Letters A*, Gentry has proposed a new static cosmological model, the “New Redshift Interpretation” (NRI), which seeks to explain the Hubble relation as a combination of gravitational and Doppler red shifts [1]. In this paper, we provide critique of the proposal, which, as we shall demonstrate, is inconsistent with both theory and observation. We shall not attempt a complete review, and will occasionally use order-of-magnitude estimates rather than more precise computations, since these are already sufficient to demonstrate that the model fails.

We begin with a very brief summary of Gentry’s proposal. The model is described as being “based on a universe governed by static-space-time general relativity,” and cannot use the expansion of spacetime to explain the Hubble red shift-distance relationship. Instead, it interprets cosmological red shifts as a combination of gravitational red shifts and ordinary Doppler shifts coming from motion in a static geometry. While the spatial geometry is never explicitly given, a number of expressions—for example, the integration measure in equation (3) of the reference—indicate that Gentry is considering a Euclidean, or at least nearly Euclidean, spatial metric.

To be consistent with observed isotropy of matter and cosmic microwave background radiation, Gentry’s model is geocentric, placing our galaxy near the center of a static spherical ball of matter with a radius $R \sim 1.4 \times 10^{10}$ light years. This matter consists of two components: ordinary pressureless matter—galaxies—with a density $\rho_m$, and vacuum energy (that is, a cosmological constant) with a density $\rho_v$ and a pressure $p_v = -\rho_v$. The gravitational potential varies with distance from the center, and the resulting gravitational red shift thus depends on distance from the Earth.

Gentry derives a “Hubble constant” $H$ of

$$H^2 = \frac{4\pi G}{3} (2\rho_v - \rho_m).$$

(1)

He computes the red shift-distance relation, combining gravitational and Doppler red shifts, to be

$$z = \frac{1 + Hr}{\sqrt{1 - (2 + u_g^2)H^2r^2}} - 1$$

(2)

where $u_g$ is a ratio of transverse to radial velocities. (We have used units $c = 1$.)

To explain cosmic microwave background radiation, Gentry supposes that his ball of matter is surrounded by a thin shell of hydrogen at a temperature of 5400 K. The resulting black body radiation must be gravitationally red shifted to the observed 2.7 K at the center of the ball. Using a matter density of $\rho_m \sim 2 \times 10^{-31}$ g/cm$^3$ and adjusting the vacuum energy to give the required CMBR red shift, he obtains a value of $\rho_v \sim 8.8 \times 10^{-30}$ g/cm$^3$.

The characteristic time scale in the NRI model is given by the radius $R$, which satisfies $HR \approx 1$. (From equation (1) of [1], it may be seen that $H^2R^2 = 1 - 2.5 \times 10^{-5}$.)

Even if we ignore time for equilibration, the universe must have an age of at least $H^{-1}$ to fill up with radiation from the hydrogen shell.
1. General Relativity

We first note that Gentry’s model, although supposedly based on general relativity, is in fact inconsistent with the Einstein field equations. The matter in the model is a perfect fluid, that is, it has no shear stresses. Any static, spherically symmetric perfect fluid in general relativity is governed by a mass relationship,

\[ \frac{dm(r)}{dr} = 4\pi r^2 \rho \]  

(3)

and the Oppenheimer-Volkov equation,

\[ \frac{dp}{dr} = \frac{(\rho + p)(m(r) + 4\pi r^3 \rho)}{r(r - 2m(r))} \]  

(4)

where \( \rho \) and \( p \) are the combined density and pressure of all of the components of the fluid \[3, 4\]. For Gentry’s model, \( \rho = \rho_m + \rho_v \) and \( p = -\rho_v \), and the constancy of \( p \) implies from \[4\] that either \( \rho = -p \) or \( m(r) = -4\pi r^3 p \). In the latter case, we can differentiate again and use \(3\), obtaining

\[ \rho_m = \begin{cases} 0 & \text{for } \rho = -p \\ 2\rho_v & \text{for } m(r) = -4\pi r^3 p. \end{cases} \]  

(5)

The first case gives an matter-free universe with a cosmological constant, and is, in fact, de Sitter space. The second yields a universe in which Gentry’s “Hubble constant” \[4\] vanishes; it may be recognized as the Einstein static universe. Neither is consistent with Gentry’s desired values of \( \rho_m \) and \( \rho_v \). Conversely, the static NRI model is not consistent with general relativity.

One might try to save the model by allowing radial dependence of \( \rho \). Such density variations are limited by observations of the interaction of cosmic microwave background radiation with distant matter, which indicate that the universe is radially homogeneous to within about 10% at the horizon scale \[3, 6\]. But even ignoring these limits, \( r \)-dependence of \( \rho \) will not help as long as the pressure \( p \) comes from a cosmological constant. Indeed, “vacuum energy” is always constrained by the Bianchi identities to be constant, and we only needed constancy of \( p \), and not \( \rho \), to obtain \(4\). The conclusion therefore stands.

Alternatively, one might drop the requirement of time-independence, although this would largely defeat the purposes of the model\[1\] The relevant Einstein tensor is then

\[\ast\]Gentry explicitly requires only time-independence of the metric, and not of the matter density and pressure. But a static metric in the Einstein field equations necessarily implies a static stress-energy tensor. Conversely, it is a trivial consequence of the field equations that a time-dependent matter distribution automatically implies a time-dependent geometry, so the claim in reference \[4\] that the model “is definitely not a static description” but is nevertheless “governed by static-space-time general relativity” is inconsistent.
given in exercise 14.16 of reference [3]. If \( \rho \) and \( p \) are taken to be independent of \( r \), it may be shown that the resulting field equations reduce to those for a standard Friedman-Lemaître-Robertson-Walker metric. This is essentially because the radial constancy of \( p \) and \( \rho \) in the region inside Gentry’s hydrogen shell together with spherical symmetry imply spatial homogeneity in this region, and isotropy around the origin plus spatial homogeneity are sufficient to determine that the metric is locally of the FLRW form [4]. The model thus reduces to a spherical piece cut out of a standard FLRW big bang model, surrounded by a now-superfluous shell of hydrogen. Such solutions have been described by Smoller and Temple [7]. They most definitely do not describe static spacetimes; the metric in the interior is indistinguishable from a standard FLRW metric. This observation explains equation (5): the de Sitter and Einstein static universes are the only FLRW cosmologies with constant pressure, the latter because it is genuinely static and the former because the energy of the vacuum remains proportional to the volume.

2. Fine Tuning

Let us ignore these theoretical problems for the moment, and assume that the model of reference [1] is a solution of some as yet unknown theory that replaces general relativity. This will cause some problems, since it is difficult to make predictions from the model without a clear theoretical framework, but we will proceed as far as we can. Our next observation is that the NRI model requires fine tuning of parameters to reproduce anything close to the observed universe. This is first evident in the choice of temperature of the hydrogen shell, which is apparently completely arbitrary and must be adjusted to reproduce the observed microwave background temperature. In the standard big bang model, by contrast, the cosmic microwave background temperature is strongly constrained by primordial nucleosynthesis [8]. Since Gentry’s model contains no mechanism for primordial nucleosynthesis, no such constraint exists.

Further careful tuning is required to obtain the velocity-distance relationship described after equation (4) of [1]. Gentry argues that a galaxy at distance \( r \) from the center of the universe experiences an acceleration

\[
\ddot{r} = -\frac{GM(r)}{r^2}\dot{r} \quad \text{with} \quad M(r) = \frac{4\pi r^3}{3} (\rho_m - 2\rho_v),
\]

where \( \rho_m - 2\rho_v = \rho + 3p \) is the effective density that contributes to the gravitational interaction in general relativity. In a vacuum energy-dominated spacetime, \( M(r) \) is negative, and the resulting acceleration is radially outward. Gentry states that equation (6) implies that \( r = r_0 \exp\{Ht\} \), where \( H \) is given by (1), and thus \( \dot{r} = Hr \).

In fact, the general solution of (6) is

\[
r = \frac{1}{2} \left[ \left( r_0 + \frac{v_0}{H} \right) e^{Ht} + \left( r_0 - \frac{v_0}{H} \right) e^{-Ht} \right],
\]
where \( r_0 \) and \( v_0 \) are the position and velocity at \( t = 0 \). The solution of reference [1] is recovered only if we require that \( v_0 = Hr_0 \). That is, the Hubble velocity-distance relationship is obtained only if it is imposed as an initial condition. Observe that this is a distinct initial condition for each galaxy: we must separately require that \( v_0 = Hr_0 \) for each object in the universe. Note also that this fine tuning is absolutely essential for the rest of the argument of reference [1], since without the resulting Doppler shift, equation (3) of that reference would give red shifts \( z \propto r^2 \) rather than \( z \propto r \) for small \( r \).

3. Stability and Consistency

We next examine several issues of stability and self-consistency of the NRI model, one involving the interior matter and others concerning the exterior hydrogen shell. We start with the observation that the “Hubble flow” (7), with Gentry’s initial conditions \( v_0 = Hr_0 \), is not consistent with a static, radially constant matter density \( \rho_m \). If we assume that \( \rho_m \) is independent of \( r \)—as required, for instance, for the force computation described in equation (6)—and set \( v = Hr \), the continuity equation gives

\[
\frac{\partial \rho_m}{\partial t} = -\nabla \cdot (\rho_m v) = -3H \rho_m \tag{8}
\]

i.e.,

\[
\rho_m(t) = \rho_m(0)e^{-3Ht} \tag{9}
\]

The matter density thus drops by a factor of 20 in the time \( H^{-1} \) it takes for the NRI universe to fill up with microwave background radiation.

Of course, equation (9) is inconsistent with the assumption of time independence used to solve (6); to do the computation correctly, one must treat (6) and (8) as coupled equations. It is not hard to show that the result asymptotically approaches (9), with \( H \) obtained from the definition (1) with \( \rho_m = 0 \). One can obtain a long period of slowly varying density by adjusting the initial value of \( \rho_m \) to be nearly \( 2\rho_v \), but the effective “Hubble constant” is then very small. In a sense, this is merely an awkward Newtonian statement of the well-known instability of the Einstein static universe: density is constant if \( \rho_m = 2\rho_v \), but any small perturbation leads to an asymptotically empty de Sitter space.

The only way we can see to avoid this time dependence would be to drop the continuity equation (8) and the consequent conservation of matter. This would require a return to something like the largely discredited steady state cosmology of Bondi, Gold, and Hoyle (see section 14.8 of reference [4]). As we shall see below, however, the NRI model is not the same as the old steady state model, but makes substantially less accurate predictions for red shifts.

We next explore the question of the stability and the radiative properties of the outer hydrogen shell in the NRI model. Local gravitational stability is not a problem: the thickness \( R_S \) of the shell can be made less than the Jeans length. But the total mass of
the shell is greater than the (negative) mass it encloses. Indeed, according to reference [1], the shell mass is
\[ M_S = 2\pi R^3 (2\rho_v - \rho_m), \]
so
\[ M_{\text{tot}} = M_S + M_{\text{interior}} = \frac{2\pi(2\rho_v - \rho_m)R^3}{3} > 0. \]  
(10)

Since the interior pressure due to the vacuum energy density is negative, it will not stabilize the shell. The time scale for collapse of an initially static shell goes as
\[ t_{\text{collapse}} \sim \sqrt{R \left( -\frac{d^2R}{dt^2} \right)^{-1}} = \frac{\sqrt{2}}{H}, \]  
(11)

where we have used equation (6) with \( M \) replaced by \( M_{\text{tot}} \). This is the same as the time scale (9) for expansion of the interior; both indicate that the NRI “Hubble constant” is actually a scale for instability.

The estimate (11) has ignored internal pressures in the shell, of course, but it seems unlikely that such pressures can stabilize a thin \((R_S \ll R)\) shell. In particular, while we have argued above that the NRI model cannot be considered general relativistic, it is interesting to note that equations (1) and (10) imply that the radius \(R\) at which the shell is located is almost exactly the Schwarzschild radius \(R_0 = 2GM_{\text{tot}}\) of the mass \(M_{\text{tot}}\):
\[ R = R_0(HR)^{-2} \approx (1 + 2.5 \times 10^{-5})R_0. \]  
(12)

We should also worry about the radiative properties of the hydrogen shell. To be opaque enough to radiate as a black body, the shell’s optical depth \(\tau\) must satisfy
\[ \tau = n\sigma R_S \gg 1, \]  
(13)
where \(n\) is the number density, \(R_S\) is the shell thickness, and \(\sigma\) is the relevant hydrogen scattering cross-section. In the likely temperature regimes for the shell in the NRI model, \(\sigma\) will be the Thomson cross-section. The mass of the shell must thus satisfy
\[ M_S = \frac{4\pi}{3} \left[ (R + R_S)^3 - R^3 \right] nm_H \approx 4\pi R^2 R_S n m_H \gg 4\pi R^2 m_H / \sigma, \]  
(14)
where \(m_H\) is the mass of a hydrogen atom. For Gentry’s value of \(R\), this gives a requirement that \(M_S \gg 3 \times 10^{24} M_\odot\).

From the discussion before equation (1) of reference [1], on the other hand, the hydrogen shell in the NRI model has a mass of only \(M_S \approx 1.3 \times 10^{23} M_\odot\), and thus will not act as a black body. Equivalently, substituting Gentry’s value of \(M_S\) into (14) and (13), we obtain an optical depth of only \(\tau \approx 0.04\). It seems impossible to adjust parameters in the model to move this number significantly upward without obtaining an unacceptably large value for the Hubble constant \(H\).

We must additionally consider radiative cooling of the hydrogen shell. The interior of the shell may be in thermal equilibrium, but according to reference [1], the exterior
spacetime is assumed to be nearly vacuum. By the Stefan-Boltzmann equation, we expect thermal energy to be radiated at a rate

$$\frac{dE_{\text{therm}}}{dt} = 4\pi R^2 \sigma_{SB} T^4,$$

(15)

where $\sigma_{SB}$ is the Stefan-Boltzmann constant. The total thermal energy, on the other hand, is approximately $\frac{3}{2} kT$ per hydrogen atom, or

$$E_{\text{therm}} = \frac{3}{2} \left( \frac{M_S}{m_H} \right) kT.$$  

(16)

The characteristic cooling time is thus

$$t_{\text{cooling}} \sim E_{\text{therm}} \left( \frac{dE_{\text{therm}}}{dt} \right)^{-1} = \frac{3kM_S}{8\pi m_H R^2 \sigma_{SB} T^3}.$$  

(17)

For the parameters of reference [1], this yields a time on the order of a second; the system is drastically unstable.

This computation is nonrelativistic, of course, and does not give the true energy radiated to infinity. Indeed, if the shell is inside its event horizon, no radiation will escape to infinity. This is irrelevant to the question of thermal stability, however. Equation (17) gives the correct cooling time in a frame comoving with the hydrogen shell. Provided that back-scattering is small—which it surely will be if the exterior spacetime is nearly empty—what matters is not what happens to the outgoing radiation after it is emitted, but merely the rate at which it leaves the shell. Even inside an event horizon, where the “outgoing” radiation converges to the singularity, the shell necessarily collapses more quickly than the radiation; relative to the shell, the radiation remains outgoing, and continues to cool the shell.

4. Observation

Finally, let us turn to the crucial question of whether the model of reference [1] agrees with observation. Gentry argues that the red shift-distance relation (2) reduces to the Hubble relation $z = Hr$ “for small $r$.” This is true if “small $r$” is small enough, but in fact, equation (3) leads to significant deviations from linearity for rather small red shifts, in regimes in which such deviations would be (and are not) seen. This effect is minimized if $u_g = 0$, but even in that case, there is about a 10% deviation from linearity for $z = .1$, and a 50% deviation for $z = .5$.

In fact, for $z < 1$, the red shift-distance relation (3) with $u_g = 0$ is well approximated by

$$z \approx (1 + z)Hr.$$  

(18)
In Gentry’s (apparently) Euclidean setting, an object with absolute luminosity \( L \) at radius \( r \) will have an apparent luminosity of

\[
\ell = \frac{L}{4\pi r^2(1 + z)}. \tag{19}
\]

The factor of \( 1 + z \) in the denominator reflects photon energy loss due to red shift; in an expanding spacetime, a second factor of \( 1 + z \) would appear in the denominator, reflecting the diminished photon arrival rate due to the stretching of the path length during travel, but this factor will not occur in a nonexpanding spacetime model like Gentry’s [9]. The luminosity distance is thus

\[
Hd_L(z) = Hr\sqrt{1 + z} \approx \frac{z}{\sqrt{1 + z}}, \tag{20}
\]

and the deceleration parameter \( q_0 \), given by [1]

\[
Hd_L = z + \frac{1}{2}(1 - q_0)z^2 + \ldots, \tag{21}
\]

is \( q_0 = 2 \). By way of reference, for an FLRW universe with \( \Lambda = 0 \), a deceleration parameter \( q_0 = 2 \) corresponds to a density four times the critical value necessary for recollapse. Even before the recent discovery that Type Ia supernovae can be used as standard candles, such a prediction was excluded by observation [9, 10]. It is now strongly ruled out by the supernova observations of Perlmutter et al. [11] and Garnavich et al. [12]. Indeed, equation (20) implies a bolometric magnitude of

\[
m \approx 5 \log_{10} z - 2.5 \log_{10}(1 + z) + \text{const.} \approx 5 \log_{10} z - 1.086z + \text{const.}, \tag{22}
\]

and a cursory look at the Hubble diagrams of references [11] and [12] shows that this prediction is in conflict with the data.

A further observational test comes from predicted number counts. Gentry argues that his model may explain the paucity of quasars at \( z > 4 \), essentially because nonlinearities in the red shift-distance relation (2) imply that a shell of width \( \Delta z \) at large \( z \) contains very little physical volume. Unfortunately, though, this fall-off actually becomes important at red shifts significantly smaller than \( z = 4 \).

In a static cosmological model, the number density \( n \) of, say, quasars can reasonably be expected to be constant. The number of objects in a shell of width \( dr \) and a solid angle \( d\Omega \) is thus \( dN = 4\pi nr^2drd\Omega \), where we have again assumed Euclidean spatial geometry. The number of objects between red shifts \( z \) and \( z + dz \) thus satisfies

\[
H^3dN = 4\pi n(Hr)^2 \frac{d(Hr)}{dz}dzd\Omega. \tag{23}
\]

For Gentry’s NRI model, \( Hr_{\text{NRI}} \) is given by equation (2), while for a standard spatially flat FLRW model, we have [9]

\[
Hr_{\text{FLRW}} = 2 \left( 1 - \frac{1}{\sqrt{1 + z}} \right). \tag{24}
\]
A straightforward computation then gives a ratio of number counts

\[ F(z) = \frac{dN_{\text{NRI}}}{dN_{\text{FLRW}}}(z) = \frac{w^2(1 - 2w^2)^{5/2}}{(1 + 2w)^4(\sqrt{1 + z} - 1)^2}, \tag{25} \]

where we define \( w = H_{\text{NRI}} / H_{\text{FLRW}} \) and consider it to be a function of \( z \) determined implicitly by equation (2).

For small red shifts, the ratio (25) is approximately \( 1 - z \), and the difference between the NRI model and a standard FLRW model is probably not presently observable. But \( F \) begins to fall substantially for larger \( z \): \( F(z = 1) \approx 0.39 \), and \( F(z = 2) \approx 0.18 \). Far from explaining the observed distribution of quasars—a sharp rise between \( z = 0 \) and \( z = 2 \), followed by a fall-off at high \( z \) \[13]\)—Gentry’s model thus predicts a substantial decrease between \( z = 0 \) and \( z = 2 \).

Next, we would like to quickly mention a few other observational issues. First, as noted above, Gentry’s model contains no mechanism for primordial nucleosynthesis. The standard big bang model successfully predicts light element abundances, and no serious alternative for the production of the observed quantities of helium and deuterium is known \[14\]. The NRI model must, apparently, attribute this success to coincidence. Second, the model has no explanation for the fairly good agreement between a variety of astrophysical ages and the Hubble time \[15, 16, 17\]. In standard cosmological models, the age of the universe sets a natural time scale for old objects, but if there is no big bang, we might reasonably expect to see objects much older than \( H^{-1} \). Third, as a “static spacetime” cosmology, the NRI model predicts a dependence of surface brightness on red shift that is very different from that of a model involving true expansion \[3\]. While the “Tolman test” of the surface brightness-red shift relation is quite difficult, there is now some evidence against static models \[18\].

Finally, let us briefly address one other issue raised in references \[2\] and \[19\], the problem of energy conservation in cosmological expansion. Gentry notes, correctly, that the electromagnetic energy of the cosmic microwave background is not conserved during expansion: in a volume expanding along with the universe, the radiation energy goes as \( (1 + z)^{-1} \), and the red shift represents a genuine loss of photon energy. But there is nothing particularly “cosmological” about this loss—a photon rising in a static gravitational potential experiences a similar energy loss. In the laboratory, there is nothing mysterious about this phenomenon, which simply reflects the need to include gravitational potential energy in one’s accounting. Indeed, energy conservation can be used to derive the red shift (see, for instance, section 7.2 of reference \[3\]).

In the cosmological context this energy accounting is more difficult, given the well-known problems in defining a local gravitational energy density in general relativity. But one can use, for example, the quasilocal energy of Brown and York \[20\] to investigate the total energy, including gravitational potential energy, in a region of an expanding universe. A quick computation shows that for a spatially flat FLRW model, the total energy inside a sphere of constant proper radius \( R \) remains constant during cosmological expansion. The extension to spatially curved universes is currently under investigation.
5. Conclusion

The “New Redshift Interpretation” of reference [1] is a radical reformulation of cosmology, which seeks to challenge the foundations of the standard big bang model. Such attempts are worthwhile; they are, after all, an important way to test existing theories. This attempt, however, clearly fails. Despite its initial appeal to general relativity, the NRI model is inconsistent with the Einstein field equations, and its theoretical foundations are unclear. If we ignore these difficulties, we find that the model requires delicate fine tuning, including a simultaneous specification of the initial velocity of each galaxy in the universe. The proposed mechanism for producing cosmic microwave background radiation fails, since the outer hydrogen shell is too thin to act as a black body, and hot and thin enough to cool in seconds from outgoing radiation. The model is unstable against both expansion of the interior matter and collapse of the outer hydrogen shell. It contains no mechanism for primordial nucleosynthesis, and cannot explain the absence of objects much older than $H^{-1}$. And finally, the predicted red shifts and quasar number counts clearly disagree with observation.

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