ANOMALOUS REDSHIFTS AND THE VARIABLE MASS HYPOTHESIS

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Abstract. There are several observations of extragalactic objects that do not appear to be consistent with the cosmological hypothesis that their redshifts arise from the expansion of the universe. These phenomena are looked at in a spacetime framework that is wider in its scope than general relativity. This framework directly incorporates the Machian notion of inertia and is conformally invariant. The consequence of this approach is that the mass of a particle may not stay constant. Two alternative viewpoints are presented to explain how large redshifts could arise from emission of radiation by particles of low masses.

1. Introduction

The velocity distance relation first announced by Hubble (1929) set the theme for the present mainstream of cosmological models. These models have the universe expanding, i.e., its typical distance scale S, separating two extragalactic objects, *increases* with the cosmic epoch t. If a typical extragalactic object, say, a galaxy G emitted light at epoch t, which is received by us today at epoch t_0, the object would exhibit a redshift z given by

$$1 + z = \frac{S(t_0)}{S(t_1)}. \tag{1}$$

Thus, if $S(t)$ has been steadily expanding, the ratio $1 + z$ will be larger, the farther back in time (t_1) we go into. Since this would also increase $(t_0 - t_1)$ and hence the distance D of the object, we have a relation of the type

Astrophysics and Space Science **244**: 177-186, 1996.

$$z = f(D), \tag{2}$$

with $f(D)$ increasing with D. The form of $f(D)$ is determined by the specific model chosen. For small D, this relation takes the linear form

$$z = \frac{DH}{c}, \tag{3}$$

where H is the Hubble constant, and c the speed of light.

This result does appear to hold, in the form (3) for nearby galaxies and (2) for distant ones. The latter has several sources of errors and uncertainties and so we cannot as yet fix the form of $f(D)$ with any degree of confidence. For first ranked cluster members, however, $f(D)$ does seem to provide a good fit with modest scatter (Kristian, et al 1978).

This has generated a confidence that the rule (2) applies to all extragalactic redshifts. This paradigm is often called the *cosmological hypothesis.* Nevertheless, there are, by now several claims by observers and theoreticians that there are situations where this paradigm does not apply. Redshifts of such objects are often referred to as *anomalous redshifts*, i.e., redshifts that don't fit into the cosmological hypothesis. We begin with a brief review of the field (*see* for details Arp 1987, Narlikar 1989).

2. Examples of Anomalous Redshifts

2.1. THE REDSHIFT MAGNITUDE RELATION FOR QSOS :

Astronomers estimate distances by using apparent magnitudes. The method works provided they are looking at a class of objects which are standard candles, i.e., objects of a fixed absolute luminosity. This seems to be the case for galaxies of elliptical type that dominate a cluster, which is the reason why the relation (2) gets verified in a redshift (z) – magnitude (m) diagram. For the quasi-stellar objects, however, the ($z - m$) diagram is a typical scatter diagram. This had been first pointed by Hoyle and Burbidge (1966) three decades ago when there were only about 100 QSOs known. Today with more than 7000 QSOs plotted on the $z - m$ diagram there is no trend discernable : certainly, there is no prima-facie correlation between m and z as predicted by the cosmological hypothesis.

2.2. QUASAR-GALAXY ASSOCIATION :

There are examples of pairs of quasars and galaxies separated by small angular deviation on the sky. Given the magnitude of the quasar we can estimate the surface density of such (or brighter) quasars on the sky. From these data we may estimate the probability of a galaxy being found within the observed angular separation purely by chance. If the probability is low (say $< 10^{-2}$) we may consider such association real. Burbidge et. al (1990) have compiled cases of such associations in which the members' redshifts do not match. Clearly if (2) holds, two objects in physical proximity of each other should have the same redshifts. If large redshift QSOs are in close proximity to bright galaxies (of low redshift) clearly the relation (2) breaks down.

2.3. CLOSE PAIRS OF QSOS :

As QSOs are rare objects (compared to galaxies) the chance of finding two QSOs with different cosmological redshifts projected within, say 60 arcsec. of each other is very small. By finding several such pairs Burbidge, Narlikar and Hewitt (1985) highlighted this anomaly.

2.4. GALAXY-GALAXY ASSOCIATION WITH CONNECTION :

Arp (1987) has pictures of pairs of galaxies in which typically a large galaxy is connected by a filament to a smaller companion. Unless the connection is fortuitous, the main and companion galaxies should show very little difference in redshift. The observed pairs, by contrast show redshift differences Δz of the order of $c\Delta z \geq 5000$ km s^{-1}. These velocity differences are too high to be explained away as velocity dispersion in a bound system. Thus the anomaly appears significant. Further, in almost all cases the companion galaxy has excess redshift whereas in a dynamical model one would expect Δz to be negative as well as positive.

2.5. COMPACT GROUPS :

Burbidge and Burbidge (1961) had highlighted the case of the discrepant redshift in the Stefan's Quintest. A few years ago Hickson (1982) compiled data on compact groups of galaxies. If these groups are real dynamically bound systems their internal velocity differences should not exceed $\sim 1000-2000$ km s^{-1}. Sulentic (1988) has analyzed the data and finds that a substantial fraction contain members with discrepant redshifts.

2.6. SPECIAL CONFIGURATIONS :

In addition there are several special alignments of QSOs as well as of QSOs with galaxies and of extraordinary concentrations of QSOs near galaxies (Narlikar 1989) to suggest their physical proximity. Yet the redshift differences are such that one cannot reconcile them with the cosmological hypothesis.

2.7. PERIODICITIES :

Recently Duari et. al (1992) have carried out several statistical analyses of QSO redshifts and they find that the period $\Delta z = 0.056$ occurs with a large degree of significance. This confirms an early result of Burbidge (1968) for same 70 QSOs (in the sample examined by Duari et. al there were ~ 30 times as many QSOs!).

It is also known from other studies (Karlsson 1977, Depaquit et. al 1985) that a periodicity of large amplitude is also present in the QSO redshifts, given by

$$\Delta \log(1+z) = \text{constant} = 0.089. \tag{4}$$

For galaxy samples Tifft (1988; and references therein), Napier (1996; and references therein) have been reporting very significant periodicities of the form $c\Delta z \approx 37.5$ km s^{-1}. All these results are clearly beyond the scope of the cosmological hypothesis.

3. The Variable Mass Hypothesis

It is always argued by the conventional supporters of the cosmological hypothesis that the data described in §2 are not a serious threat to the cosmological hypothesis because of one or more of the following reasons :

a) There are subtle selection effects that are not taken into account,

b) Probabilities for observed configurations are computed a-posteriori and hence they don't mean much,

c) Effects like gravitational lensing can explain dense concentrations,

d) The observed connections are not real.

These issues, pros and cons of the cosmological hypothesis and alternative explanations that go beyond the cosmological hypothesis have been discussed by Narlikar (1989). My purpose here is to accept the reality of at least some of the anomalous effects and look for an explanation. Here I will talk of a redshift that arises from variability of masses of elementary particles in a Machian theory of gravity. Such a theory was proposed by Hoyle and Narlikar (1964, 1966) and its basic features are as follows.

Mach's principle broadly states that the inertia of matter arises from other matter in the universe. To put the statement in a mathematical form Hoyle and Narlikar (op. cit.) assumed that the spacetime geometry is Riemannian with metric

$$ds^2 = g_{ik} dx^i dx^k \tag{5}$$

for coordinates $x^i[i = 0, 1, 2, 3; x^0$ timelike, signature $(+ - - -)]$.

Now imagine particles of matter labeled $a, b, c, \ldots$ with x_a^i the coordinates of the a^{th} particle, whose worldline will be denoted by Γ_a. Then the 'mass-function' $m(X)$ at a world point X is defined as the contribution to inertia at X, of all particles $a, b, \ldots$ etc. :

$$m(X) = \sum_a m^{(a)}(X) \tag{6}$$

where

$$m^{(a)}(X) = \int_{\Gamma_a} G(X, A) ds_a. \tag{7}$$

Here the inertia at X due to particle a is communicated by the propagator $G(X, A)$ which satisfies a conformally invariant wave equation. The simplest form of such an equation is

$$\Box m^{(a)} + \frac{1}{6} R m^{(a)} = N^{(a)} \tag{8}$$

where $\Box$ is the wave operator, R the scalar curvature and $N^{(a)}$ the number density function of particle a at point X.

The dynamical equations of this theory are derived from the variation of a simple action :

$$\sum_a \int m_a(A) ds_a, \tag{9}$$

where

$$m_a(A) = \sum_{b \neq a} m^{(b)}(A). \tag{10}$$

The action (9) may be varied with respect to g_{ik} to get the field equations and with respect to particle worldlines to get the equations of motions. The former gives, in the many particle approximation

$$\frac{1}{2} m^2 (R_{ik} - \frac{1}{2} g_{ik} R) = -3T_{ik} + m\{g_{ik} \Box m - m_{;ik}\} + 2\{m_{,i} m_{,k} - \frac{1}{4} g_{ik} m^{,l} m_{,l}\}. \tag{11}$$

These equations allow us to talk of a variable inertial mass. Since the equations are conformally invariant, we may be able to choose a conformal frame in which $m =$ constant. In such a frame (11) becomes

$$R_{ik} - \frac{1}{2} g_{ik} R = -\frac{6}{m^2} T_{ik}, \tag{12}$$

identical with those of general relativity if we identify

$$\frac{8\pi G}{c^4} = \frac{6}{m^2}, \tag{13}$$

G being the Newtonian gravitational constant.

However, this transformation breaks down if we choose part of spacetime which has $m = 0$. Indeed, one can show that the spacetime singularities of general relativity are due to the 'forcing' of equations (11) into the more compact form (12) even when $m = 0$ hypersurfaces exist (Kembhavi 1978). It is at such hypersurfaces that relativistic singularity is found. As we shall see later, one can avoid referring to the equations (12) and their singular solutions and instead use the nonsingular equations (11).

This is when we encounter a new interpretation for redshift that applies equally well to the regular as well as the anomalous situations.

4. A Flat Spacetime Solution

We illustrate this statement with the flat spacetime solution of the equations (11). It can be easily verified that the solution of these equations is given by the Minkowski metric

$$ds^2 = c^2 dt^2 - dr^2 - r^2(d\theta^2 + \sin^2 d\phi^2), \tag{14}$$

with the mass function

$$m = at^2, \qquad a = \text{constant}; \tag{15}$$

the number density of particles being constant in the comoving reference frame (r, θ, ϕ).

We have here a flat spacetime cosmology in which light waves travel without spectral shift. How then do we explain redshift? Consider a galaxy G at a given radial coordinate r, the observer being at $r = 0$. A light ray leaving the galaxy at $t_0 - r/c$ reaches the observer at time t_0. Since the masses of all subatomic particles scale as t^2, the emitted wavelengths go as $m^{-1} \propto t^{-2}$. Hence we get the factor

$$1 + z = \frac{t_0^2}{\left(t_0 - \frac{r}{c}\right)^2} \tag{16}$$

as the ratio of the wavelength *actually emitted* by the galaxy to the wavelength emitted in the laboratory of the observer. As such the observed cosmological redshift is the consequence of the systematic increase in particle masses with the t-epoch.

This solution is observationally *no different* from the Einstein de Sitter model of standard relativistic cosmology because we can effect a conformal transformation that makes the mass function constant by choosing a conformal function $\propto t^2$. Thus, writing

$$ds_R \propto t^2 ds \tag{17}$$

the line element in the *relativistic frame* ds_R^2 becomes the familiar Einstein de Sitter line element if we make the coordinate transformation

$$t \propto \tau^{1/3}, \qquad t_0 = 3\tau_0. \tag{18}$$

The present value of the Hubble constant in the model is $H_0 = 2/t_0$.

Notice that in a well behaved conformal transformation the conformal function should not vanish or become infinite. Here we have to pay the price of choosing a conformal function that vanishes at $t = 0$: for in the relativistic frame the $\tau = 0,\ t = 0$ hypersurface has the (big bang) singularity.

The flat spacetime cosmology admits anomalous redshifts in a natural way, as was shown by Narlikar (1977), hereafter *Paper I.* Suppose the zero mass hypersurface has a kink as shown in Figure 1. The worldline of a QSO, Q (say) intersects it at an epoch $t_1 > 0$. As shown in Paper I, the particle mass function in Q starts ticking from *this epoch.* Thus at an epoch $t > t_1$ it will be $\propto (t - t_1)^2$. The interpretation of this result is simple; the particle receives all inertial contributions of $1/r$ type from a past light cone extending from t to t_1.

In Figure 1 we see a QSO, Q, and a galaxy, G, both close neighbours but the worldline of Q passes through the kink while that of G does not. For particles in G the mass function is $\propto t^2$ at epoch t. If both Q and G are at a distance r from the observer, formula (16) gives the respective redshifts as

$$1 + z_Q = \frac{t_0^2}{(t_0 - r/c - t_1)^2}, \qquad 1 + z_G = \frac{t_0^2}{(t_0 - r/c)^2}. \tag{19}$$

So we have $z_Q > z_G$ and an anomalous redshift for the QSO! Narlikar and Das (1980), hereafter *Paper II*, considered such pairs.

As illustrated in Figure 1, the worldlines of Q and G continue on both sides of the zero mass hypersurface. However, the appearance of $m = 0$ corresponds in the relativistic frame to the spacetime singularity, thus giving an incomplete (and erroneous) view of a universe 'beginning' at $\tau = 0$. In practice we may interpret the Figure 1 as describing a QSO ejected from the neighbour galaxy. *Paper II* had given a detailed dynamical study of such pairs.

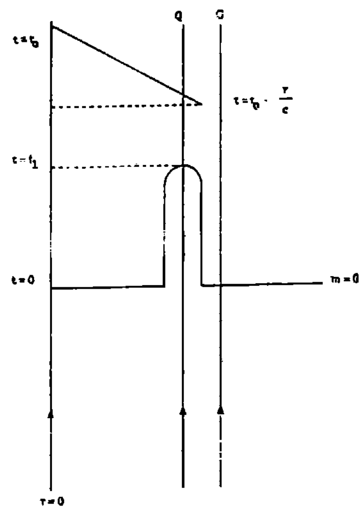

Figure 1. Spacetime diagram showing the worldlines of a QSO Q and a galaxy G crossing the zero mass hypersurface. The latter crosses the hypersurface at $t = 0$ while the former crosses it at $t = t_1 > 0$. The hypersurface has a kink which raises it from the generic value $t = 0$ to a local value $t = t_1$.

Stability : How can a static, matter-filled universe remain stable? Would it not collapse as Einstein (and even earlier Newton) found? The answer is that stability is guaranteed by the mass dependent terms on the right hand side of (11). Small perturbations of the flat Minkowski spacetime would lead to small oscillations about the line element (14) rather than to a collapse.

Quantized redshifts : Redshifts which arise from a difference in age, however, could solve the quantization problem in a natural way. Creation processes which produce galaxies at different times must originate at a zero mass surface. Close to the zero mass surface the classical action is very small and hence physics is dictated by quantum considerations. Thus one could argue that the material that emerges from the zero mass surface, emerges within a quantum mechanical realm and may do so in discrete bursts spaced at discrete intervals instead of continuously. This could lead to a quantized distribution of redshift intervals.

For example, consider a small variation of t_1 in Eq. (19), which leads to a variation of z :

$$\frac{\Delta z_Q}{1 + z_Q} = \frac{2\Delta t_1}{t_0 - r/c - t_1}. \tag{20}$$

Thus a small difference in the epoch of creation would lead to a small difference in the observed redshift. For the nearby samples considered by Tifft (op. cit.) the redshifts are small. Thus we set $z_Q \approx 0$ and neglect r/c and t_1 in (20) in comparison with t_0. Thus we get

$$\Delta z_Q \cong \frac{2\Delta t_1}{t_0} = H_0 \Delta t_0 \tag{21}$$

This tells us that quantized steps of $c\Delta z_Q = 37.5\ \mathrm{km\,s^{-1}}$ arise from spacings in the epochs of creation, of magnitude $(8000)^{-1}$ of the Hubble time scale H_0^{-1}.

Although this is at the moment only a crude suggestion, the alternative of trying to explain the observed quantization in a velocity-only universe seems quite daunting.

This explanation must assume that there are no other 'contaminating' redshift contributions such as the Doppler or gravitational ones which would spoil the observed exact periodicity. This remains a serious difficulty of the present explanation as, indeed of any other explanation of this effect.

5. Alternative View of Burbidge and Hoyle

As mentioned above the crucial element of the idea is that *new matter appears with anomalously high redshift.* Hoyle and Burbidge (1996) on the other hand have argued that *the anomalously redshifted matter must be very old.* The interpretation is based on the quasi-steady state cosmology (QSSC) of Hoyle, Burbidge and Narlikar (1993, 1994 a,b, 1995). I give a brief description here of how the Burbidge-Hoyle scheme operates.

The QSSC has no beginning and no end on the time axis and its scale factor is given by

$$S(t) = e^{t/P}\left\{1 + \alpha \cos\frac{2\pi t}{Q}\right\}, \tag{22}$$

where P, Q are time scales while α is a dimensionless parameter with $|\alpha| < 1$. We will take $\alpha > 0$. Typically $P \approx 20Q$, $Q \approx 40 - 50$ Gyr. The universe, in this model, has a long-term (P) trend of expansion superposed with alternative cycles of contraction and expansion (with period Q). The dynamics are controlled by (and in turn control) the matter creation process going on near collapsed massive objects. These occur predominantly near minima of S.

Now consider a species of particles created at a typical minimum given by

$$T = T_r = -\left(r + \frac{1}{2}\right)Q \tag{23}$$

where r is an integer > 0. The most recent minimum corresponds to $r = 0$.

Now the particles created at $t = t_r$ will acquire the mass contribution from all existing particles, but not from particles created at $t > t_r$. Thus if we observe the universe from the present epoch which lies in the cycle beginning at T_0, we will see particles created at $T_1, T_2, T_3, \ldots$, but with masses in decreasing order. The masses turn out to be in a geometric series with common ratio (of decrease from one term to next) of exp $(-Q/P)$. Consequently, the redshifts of objects made of these particles will systematically increase in a geometric series with $(1+z)$ rising at each term by a fraction exp (Q/P). This interpretation thus has the advantage of having $\Delta \log(1+z) =$ constant in a natural way.

6. Conclusion

It is too early to comment on the merit or disadvantage of either of the interpretations. What is needed are further observations to decide whether the anomalously redshifted matter is systematically younger or the other way round, compared to standard matter.

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