NONCOSMOLOGICAL REDSHIFTS : THEORETICAL ALTERNATIVES

Jayant V. Narlikar
Tata Institute of Fundamental Research
Bombay 400005, India

Abstract. Starting from the various alternative theoretical interpretations offered for redshifts, this paper describes two models in some detail. The first model belongs to conventional physics and makes use of the Doppler effect. The second model makes use of the variable mass hypothesis arising from the Hoyle-Narlikar theory of gravitation. Some observable consequences of these models and testable predictions are briefly outlined.

Introduction

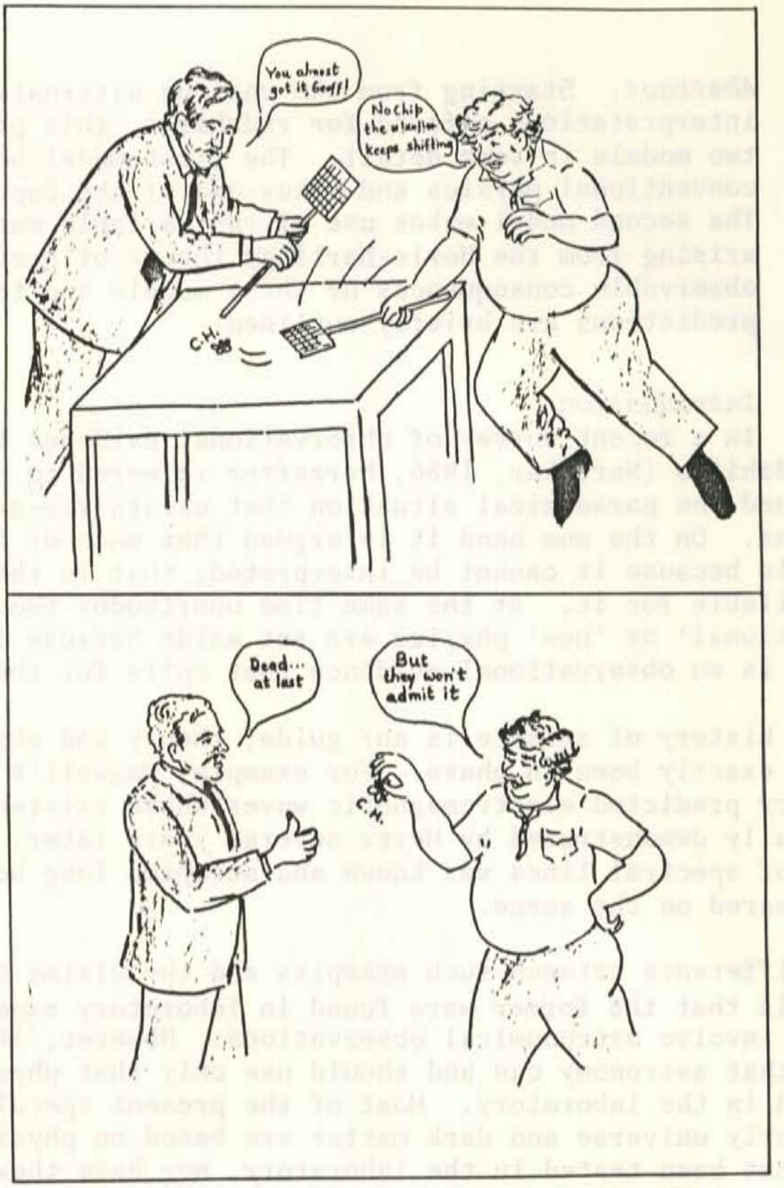
In a recent survey of observational evidence for noncosmological redshifts (Narlikar, 1986, hereafter referred to as Paper I). I had mentioned the paradoxical situation that exists vis-a-vis theory and observations. On the one hand it is argued that much of the evidence is unacceptable because it cannot be interpreted, that is there is no theory available for it. At the same time unorthodox theories belonging to 'conventional' or 'new' physics are set aside because it is claimed that there is no observational evidence that calls for them.

Indeed, if history of science is any guide, theory and observations have never exactly been in phase. For example, Maxwell's electromagnetic theory predicted electromagnetic waves whose existence was experimentally demonstrated by Hertz several years later. Likewise, the existence of spectral lines was known and accepted long before quantum theory appeared on the scene.

The only difference between such examples and the claims of anomalous redshifts is that the former were found in laboratory experiments while the latter involve astronomical observations. However, it can no longer be argued that astronomy can and should use only that physics that has been tested in the laboratory. Most of the present speculations about the very early universe and dark matter are based on physical theories that have not been tested in the laboratory, nor have they yet come up with any observable consequences. Anomalous redshifts at least provide concrete observations of the present-day universe that can be checked and rechecked.

The cartoon shown in Figure 1 illustrates the frustrating situation concerning the cosmological hypothesis (CH). Awkward observations are

Figure 1 : Chip Arp and Geoffrey Burbidge trying to kill the fly CH.



either 'wished away' on the grounds of statistics not always sound, as found in the case of the Arp-Hazard triplets (Edmunds and George, 1982; Narlikar and Subramanian, 1982) or artificially reinterpreted as, for example, in the case of the quasar found near the galaxy 2237+0305 (Huchra, et al, 1985, Burbidge, 1985).

To fix ideas I will define CH as the statement that the entire redshift z of any extragalactic object arises from the Hubble's law. To allow for some flexibility one may permit Doppler redshifts of upto ~ 500 kms^{-1} as are observed in clusters of galaxies. One may allow a gravitational redshift component of comparable magnitude if the light has to climb out of potential wells typical of galaxies or clusters.

The alternative to CH, the noncosmological hypothesis simply states that a substantial part of the redshift of at least a few extragalactic objects are of noncosmological nature. Specifically one may write

$$1 + z = \left(1 + z_c\right)\left(1 + z_{NC}\right) \tag{1}$$

where z_c is cosmological (arising from the expansion of the universe) and z_{NC} is due to some other causes. The killing of the fly in Figure 1 amounts to admitting that $z_{NC} \neq 0$. To get out of the vicious circle described in the first paragraph of the article, I will assume that the present evidence (e.g. that reviewed in Paper I) warrants this assumption. What theoretical alternatives then exist for noncosmological interpretations?

The alternatives may be divided into two classes: the first is limited to known physics while the second calls for new physics. To the first class belong the two well known alternatives of Doppler and gravitational redshifts. The second class is necessarily open but the alternatives often discussed in it are the variable mass hypothesis (VMH) of the Hoyle-Narlikar theory of gravity and the tired light theory discussed in this conference by Vigier and Pecker. In the present talk I will describe the first of these alternatives in each class.

The Doppler Hypothesis

Proposed by Terrell (1964) soon after the first two quasars were discovered, the Doppler hypothesis has undergone a few modifications. Instead of arguing that quasars were ejected from the centre of the Galaxy, as Terrell had proposed, Hoyle and Burbidge (1966) suggested that they were ejected from active galactic nuclei. Such nuclei provide manifest signs of explosions and are more plausible candidates for ejectors of quasars then the relatively sedate nucleus of our Galaxy. However, this hypothesis immediately ran into the difficulty of the apparent absence of blueshifted quasars. Indeed, as first demonstrated by Strittmatter (1967) the blueshifted quasars should far outnumber the redshifted ones (because of their brightness) in a flux limited sample. To get round the difficulty Strittmatter had suggested that quasars might be emitting light preferentially in the backward direction.

Subsequently Hoyle (1980) calculated that a quasar moving with velocity V with respect to the cosmological rest frame (CRF) and emitting radiation in a backward cone of angle

$$\theta = 2 \cos^{-1} \frac{c-\sqrt{c^2-V^2}}{V}, \quad V = |\underset{\sim}{V}|, \tag{2}$$

in its rest frame would never be seen blueshifted by any observer stationary in the CRF. What physical process, however, would limit the quasar to radiate backwards?

Three motion-dependent alternatives suggest themselves. Hoyle's own suggestion (op.cit) was that piled up plasma in the forward direction would absorb quasar's radiation so as to make it invisible from the front. In practice this does not work because the intergalactic medium (IGM) is not dense enough to cause effective absorption. A second possibility is suggested by the adaptation of a model of Rudermann and Spiegel (1971) in which the quasar may focus incoming IGM into a dense wake which would radiate. Again, putting actual numbers into the problem shows that the mechanism does not work. The details of both these calculations are given in a paper by myself and Subramanian (1983) which is mainly concerned with exploring a third alternative that does work. Hereafter this paper will be referred to as Paper II.

The idea is based on a modification of the twin exhaust model of Blandford and Rees (1974). In the original Blandford-Rees model the source, which is a massive object (either a compact one like a black hole or a dense star cluster) surrounded by a plasma cloud develops a twin deLaval nozzle along the line of least resistence through the cloud (which happens to be its axis of rotation). Plasma is squirted out in highly collimated jets in opposite directions.

When this model is viewed in the case of a quasar ejected at high speed through the IGM a modification becomes necessary. The line of least resistence is now the backward direction, where the jet should emerge. The ram pressure of the IGM (moving relativistically relative to the quasar) is high enough to prevent a forward jet from developing. The highlights of the model are as follows.

To begin with, the model has four alternative scenarios. The central gravitating source in the ejected quasar for example could either be a uniform starcluster (Type I) or a compact massive object (Type II). For each of these two source types the IGM could interact with the gas cloud in two ways: Case A: it goes clean through it, or Case B: it produces a bow shock. Figure 2 illustrates one of these four scenarios.

Several questions arise when this model is investigated in detail. I mention some below:

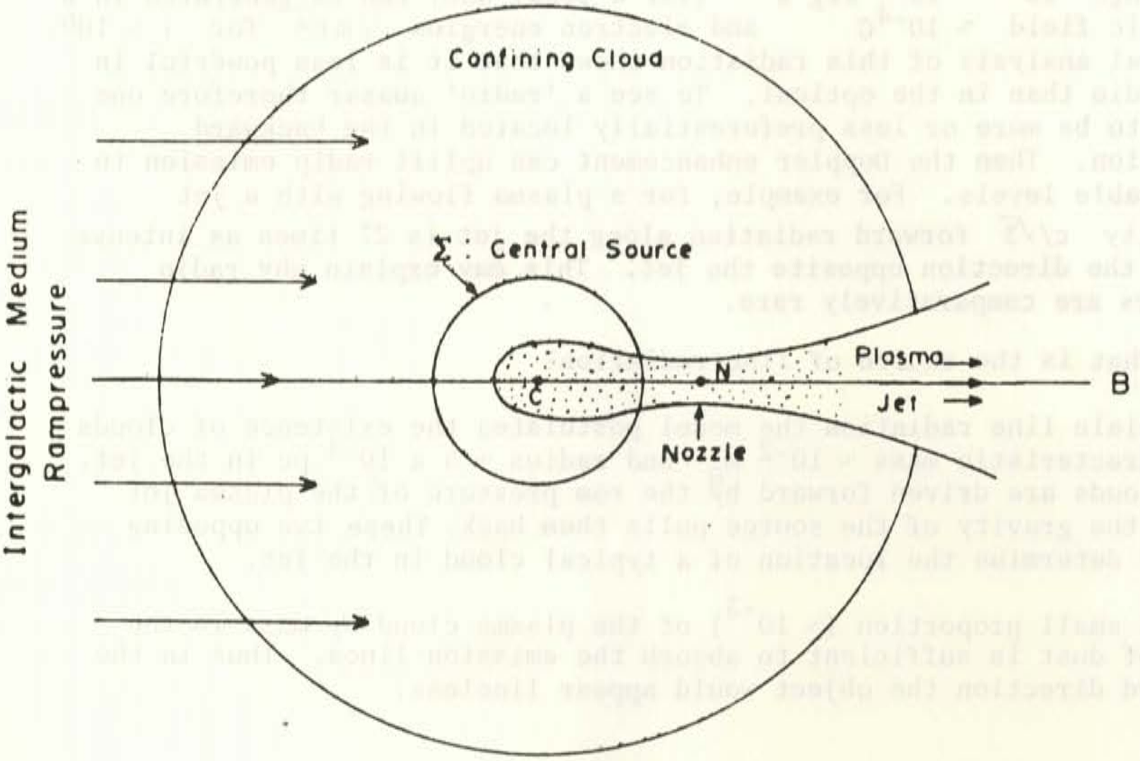
a) Can the gas cloud remain intact in spite of its motion at high speed against the IGM?

The answer to this question is 'yes' provided the gravitational binding of the cloud is sufficiently strong. The inequalities expressing this condition for all the four scenarios are described in Paper II.

b) Does the IGM distort the internal composition of the gas cloud?

Again, details given in Paper II indicate that the answer is 'No', provided certain inequalities are satisfied.

Figure 2 : The components of the quasar model where the gravitating mass is a compact object. The jet is in backward direction. The dots denote emission line clouds.



c) How is the jet formed?

Here the scenario differs between the two cases A and B. In case A, the plasma would have magnetic fields which would stop the incoming IGM through a collisionless shock. The plasma then 'feels' the IGM pressure and begins to decelerate. The resistence to the plasma progressively drops as one goes over from the forward to the backward direction. The plasma then seeks the way out along the line of least resistence and thus forms a backward jet.

In Case B, transient pressure gradients are set up impeding plasma expansion in the forward direction while accelerating it in the backward direction. When the transient effects are over (within $\sim 10^4$ yrs) the plasma keeps flowing along the backward direction along the channel scooped out by the initial jet.

d) What is the size of the jet? What are its other physical parameters?

Adaptation of the Blandford-Rees model gives the answer to this question. Details are worked out in Paper II for all four cases. The model for local quasars is, of course, a scaled down version of the Blandford-Rees model.

e) Where does the continuum emission come from?

Calculations using a synchrotron model suggest that the luminosity in the range 10^{41} - 10^{41} erg s^{-1} (for a local QSO) can be generated in a magnetic field $\sim 10^{-4}$G and electron energies $\gamma m c^2$ for $\gamma \sim 10^6$. Spectral analysis of this radiation shows that it is less powerful in the radio than in the optical. To see a 'radio' quasar therefore one needs to be more or less preferentially located in the backward direction. Then the Doppler enhancement can uplift radio emission to observable levels. For example, for a plasma flowing with a jet velocity $c/\sqrt{3}$ forward radiation along the jet is 27 times as intense as in the direction opposite the jet. This may explain why radio quasars are comparatively rare.

f) What is the source of line radiation?

To explain line radiation the model postulates the existence of clouds of characteristic mass $\sim 10^{-2}$ $M_\odot$ and radius $\sim 5 \times 10^{-4}$ pc in the jet. The clouds are driven forward by the ram pressure of the plasma jet while the gravity of the source pulls them back. These two opposing forces determine the location of a typical cloud in the jet.

Only a small proportion ($\sim 10^{-3}$) of the plasma cloud by mass in the form of dust is sufficient to absorb the emission lines. Thus in the forward direction the object would appear lineless.

These questions and their answers indicate that a viable Doppler model can be constructed in sufficient detail to make it testable as a realistic hypothesis. What tests can one use? A few are suggested below.

(i) Of course, the most direct test is the detection of proper motions. VLBI techniques capable of measuring angular proper motions of 0.5-5 m arc-s yr^{-1} against the cosmological rest frame should detect the effect especially if the quasars are closer than ∿ 100-300 Mpc.

(ii) The quasars should as a rule have only one jet. Observations to date support this conclusion. Proper motions, if detected, should be opposite to the direction of the jet.

(iii) The cloud surrounding the quasar should be detected as a fuzz. The larger the redshift, the smaller are the physical dimensions of the cloud and hence the shorter the fuzz.

(iv) The apparent rarity of radio loud quasars is understood naturally by the Doppler model.

(v) The alignments of quasars or their location near low redshift galaxies may be understood as the Doppler ejection phenomenon.

The Variable Mass Hypothesis

More than two decades ago Fred Hoyle and I (1964) proposed a theory of gravitation that explicitly incorporated Mach's Principle (1893) That is, it started with the assumption that a long range scalar interaction between any two particles in the universe generates inertia for each of them. Thus the total inertial mass m_a of any particle a can be written as the sum of inertial contributions $m^{(b)}$ from all other particles in the universe.

$$m_a = \sum_{b \neq a} m^{(b)} \qquad (3)$$

Apart from this input which quantifies Mach's principle, this theory (hereafter called the HN theory) assumed the curved spacetime framework of general relativity, as well as that the mass-interaction (3) is conformally invariant. The following important result then emerges from the theory:

If the solution of any gravitational problem is described by inertial masses m_a,--- and the spacetime metric g_{ik} (i,k = 0,1,2,3) then the same problem can also be described by another solution in which the particle masses are $m_a\ \Omega^{-1}$,--- and the metric is $\Omega^2\ g_{ik}$, for any well behaved function $\Omega > 0$. (Hoyle and Narlikar, 1966).

In the simplest set of solutions the function Ω , called the conformal function, can be so chosen as to make all particle masses constant. The theory then becomes identical to general relativity. However, as shown by A.K. Kembhavi (1978) the 'constant mass' constraint is an artificial one. In particular, if a hypersurface in the original solution had all particle masses vanishing, then the above conformal transformation to general relativity leads to that hypersurface becoming singular. Thus the inevitability of spacetime singularity in general relativity is seen in the HN theory as being due to the existence of zero-mass hypersurfaces.

To illustrate this effect consider the standard $k = 0$ Friedman model, given by

$$ds_F^2 = dt^2 - \left(\frac{3t}{2}\right)^{4/3} \left[dr^2 + r^2\,(d\theta^2 + \sin^2\theta d\phi^2)\right] \qquad (4)$$

where we have taken the Hubble constant at the present epoch ($t = 2/3$) to be unity. This spacetime manifold is singular on the hypersurface $t = 0$.

However, this is a conformal transform of the flat spacetime given by the Minkowski line element

$$ds_M^2 = d\tau^2 - \left[dr^2 + r^2\,(d\theta^2 + \sin^2\theta d\phi^2)\right] , \qquad (5)$$

where

$$\Omega = \left(\frac{3t}{2}\right)^{2/3} , \quad \tau = (12t)^{1/3} . \qquad (6)$$

In the HN cosmology, a homogeneous isotropic universe is described in its simplest form by the line element (5) but with particle masses given by

$$m(\tau) = \mu\tau^2 , \quad \mu = \text{constant} . \qquad (7)$$

The masses all vanish on the hypersurface $\tau = 0$, which is the same as the singular hypersurface $t = 0$ of the standard model. The insistance that all masses be constant forces the relativistic solution to have an unphysical Ω that vanishes on $t = 0$ leading to a spacetime singularity. The big bang of standard cosmology thus corresponds to the zero mass epoch in the HN cosmology.

In general the HN cosmology has variable mass solutions with $m = 0$ hypersurfaces occurring now and then. All such hypersurfaces lead to singular geometries if one forces on the spacetime a conformal function that makes masses constant.

Returning to the Minkowski solution, it is easy to see how redshifts arise in the HN theory. A galaxy G_o at $r = 0$, $\tau = \tau_o$ views another G, at $r > 0$, when its epoch was $\tau = \tau_o - r$ (we have taken $c = 1$ here). The particle masses at this epoch were systematically smaller than those in G_o at τ_o. Hence the spectral wavelengths of lines in G's radiation will be systematically longer than those measured in a locally generated radiation by an observer in G_o. Using (7) we get the observed redshift as

$$z_G = \left(\frac{\tau_o}{\tau_o - r}\right)^2 - 1. \tag{8}$$

Thus redshifts can be produced without cosmological expansion, from variable particle masses. This is the Variable Mass Hypothesis (VMH).

Notice that unlike the Friedman solution the $m = 0$ hypersurfaces allow the spacetime to be extended to $\tau < 0$. There is no corresponding pre-big bang era ($t < 0$) in standard cosmology. Later work (Narlikar 1977) showed that redshift anomalies can occur when such hypersurfaces develop kinks.

The effect of a kink is illustrated in Figure 3. Imagine the worldlines of the observer galaxy G_o and the source galaxy G crossing the zero mass hypersurface at $\tau=0$. The galaxy G has a neighbour quasar Q whose worldline crosses the $m = 0$ hypersurface at $\tau = \tau_Q > 0$. Particle masses in Q change according to the rule

$$m = \mu\,(\tau - \tau_Q)^2. \tag{9}$$

Hence the quasar redshift as measured at G_o is

$$z_Q = \left(\frac{\tau_o}{\tau_o - \tau_Q - r}\right)^2 - 1, \tag{10}$$

with the result that $z_Q > z_G$. Thus Q has an anomalous part $z_{NC} > 0$.

In physical terms thus result has the following interpretation. We may in loose terms consider the epoch $m = 0$ as one of creation although, as shown in Figure 3, the worldlines of particles existed prior to it. Thus bulk of the matter in the universe had $m = 0$ at $\tau = 0$. The 'later creation' in the kink may be thought of as occurring in a minor explosion at certain isolated spots in the universe. The quasar Q in the above example could be considered as fired out of the nucleus of the neighbouring galaxy G.

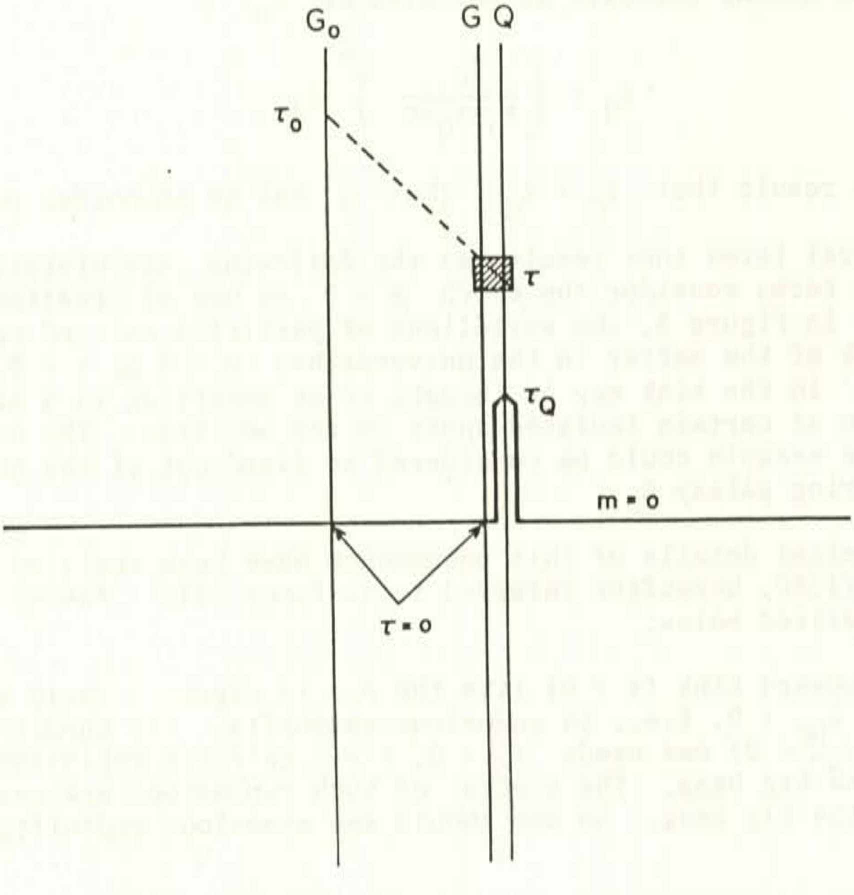
The dynamical details of this phenomenon have been analysed by Narlikar and Das (1980, hereafter referred to as Paper III). The salient points are summarised below.

a) An upward kink ($\tau > 0$) like the one in Figure 3 would inevitably lead to $z_{NC} > 0$, i.e., to anomalous redshifts. For anomalous blueshifts ($z_{NC} < 0$) one needs $\tau_Q < 0$, i.e., galactic explosions to occur before the big bang. The ejecta of such explosions are unlikely to survive the big bang. So one should see anomalous redshifts only.

b) If the galactic explosions occurred soon after the big bang, i.e. if $\tau_Q \ll 1$, then we expect the anomalous component of the redshift to be small. We may consider the anomalous redshifts of companion galaxies observed by Arp and others to arise in this way. The companion galaxies are thus the evolved states of quasars. Present day quasars may likewise acquire galactic forms at later epochs.

c) Since the particles at the creation epoch have zero rest mass, they initially travel with the speed of light. Can such particles remain trapped in the gravitational field of the parent galaxy? Narlikar and Das (op. cit) find that since the mass of the ejected object rapidly

Figure 3 : The 'upward' kink in the (r, τ) plane in the zero mass hypersurface has a quasar worldline (Q) passing through it at $\tau = \tau_Q$. The neighbouring galaxy (G) has its worldline passing through the hypersurface at $\tau = 0$.



grows, it slows down. Denoting by η the time elapsed since the explosion, it can be shown that the relativistic time dilatation factor γ for the ejected mass declines in the early stages as

$$\gamma \sim \left(\frac{\eta_o}{\eta}\right)^2 \left(1 + \frac{\eta^4}{\eta_o^4}\right)^{1/2}, \qquad (11)$$

where η_o is a constant of the motion.

It is clear that whether the quasar escapes the galaxy or remains trapped in it depends on the magnitude of η_o, and on the mass M of the parent galaxy. For each M one finds that there is a critical η_c such that for $\eta_o < \eta_c$ the quasar has already got into a bound orbit around the galaxy at the time of its observation (τ). For $\eta_o > \eta_c$ the quasar has either escaped altogether, or its 'turn round time' is later than the epoch τ at which it was observed.

For a bound highly eccentric orbit one may calculate the maximum separation R_{max} between G and Q. R_{max} depends on z_Q and M. For example, for $M = 10^{11} M_{\odot}$, $z_Q = 2$ we have $\eta_c = 1.03 \times 10^{-5}$ and $R_{max} = 398$. For the same mass $z_Q = 0.5$ leads to $R_{max} = 449$. Thus R_{max} decreases slowly as z_Q increases. It is also found that $R_{max} \propto M^{1/3}$ and that it decreases slowly with z_G.

d) It could be argued on the basis of the VMH that all quasars were so created through delayed galactic explosions and that the bound quasars are the ones showing anomalous redshifts. Quasars which have escaped are seen as field quasars.

The VMH can be tested observationally in a number of ways. Some are indicated below.

(i) The typical Q - G separation will be less than R_{max} for two reasons. At the time of observation the quasar need not be at maximum separation. Moreover, for a highly eccentric orbit the projected separation perpendicular to the line of sight will be less than R_{max}. Averaging with respect to position on the orbit and projection angles suggests that typical separation may be ∿ 10% of the R_{max} value. Since R_{max} slowly decreases with z_G we expect θ to drop as $z_G^{-1-\delta}$ where δ is small and positive. Likewise we expect θ to decrease slowly with z_Q. In Paper III it is shown how these expectations are borne out by observations.

(ii) If a number of quasars are ejected in a single explosion we expect them to have the same redshift. Also two quasars so ejected would be aligned across the galaxy with equal redshifts. Observations of this type have been reported from time to time (see for example, Arp et. al 1979, Arp 1980, also, Paper I).

(iii) The Arp-Hazard triplets (Arp and Hazard, 1980) can be given a novel interpretation in VMH. The well aligned triplets have redshifts

(2.15, 0.51, 1.72) and (2.12, 0.54, 1.61). The corresponding members of the two triplets have nearly the same redshifts! By joining their positions we find that they could have been ejected in a triple explosion from a compact region. This region should be searched for post-explosion remnants.

(iv) Evidence for smaller particle masses in higher redshift quasars could also come from the astrophysics of these objects. For example, in a given magnetic field a less massive electron would generate greater synchrotron luminosity than a more massive one.

Concluding Remarks

These two models illustrate what may be possible by way of theoretical interpretation of noncosmological redshifts. Further work needs to be done in both the models so far described. For example, one needs to know more about the ejection process in the Doppler model. The VMH might throw some light on the periodicities observed in redshift distributions (Hewitt and Burbidge 1986, Depaquit et al 1985, Tifft, 1987), through the phenomenon of quantization of particle masses.

Whatever be the ultimate fate fate of such theories they serve a useful purpose in breaking the vicious circle mentioned in the beginning of this contribution.

References

Arp, H. (1980). Ap. J. 236, 63.
Arp, H. and Hazard, C. (1980). Ap.J. 240, 726.
Arp, H., Sulentic, J.W. and di Tullio, G. (1979). Ap. J. 229, 489.
Blandford, R.D. and Rees, M.J. (1974). M.N.R.A.S. 164, 395.
Burbidge, G.R. (1985), A.J. 90, 1399.
Depaquit, S., Pecker, J.-C. and Vigier, J.-P. (1985). Astronom. Nach., 306, I, 7.
Edmunds, M.G. and George, G.H. (1981). Nature. 290, 481.
Hewitt, A. and Burbidge, G.R. (1986). A new catalogue of quasistellar objects. In Quasars, ed. G. Swarup and V.K. Kapahi, pp.51-52 Dordrecht : D.Reidel Publishing Company.
Hoyle, F. (1980). Astrophysics and Relativity, Preprint 63, Cardiff: University College.
Hoyle, F. and Burbidge, G.R. (1966), Ap. J. 144, 534.
Hoyle, F. and Narlikar, J.V. (1964). Proc. Roy. Soc. A 282, 191.
Hoyle, F. and Narlikar, J.V. (1966). Proc. Roy. Soc. A 294, 138.
Huchra, J., Gorenstein, M., Kent, S., Shapiro, I., Smith, G., Horine, E. and Perley, R. (1985). A.J. 90, 691.
Kembhavi, A.K. (1978). M.N.R.A.S. 185, 807.
Mach, E. (1893). The Science of Mechanics. London : Watts & Co.
Narlikar, J.V. (1977). Ann. Phys. 107, 325.
Narlikar, J.V. (1986). Noncosmological redshifts. In Quasars, ed. G. Swarup and V.K. Kapahi, pp. 463-473. Dordrecht: D.Reidel Publishing Company. (Paper I).

Narlikar, J.V. and Das, P.K. (1980). Ap. J. 240, 401 (Paper III).
Narlikar, J.V. and Subramanian, K. (1982). Ap. J. 260, 469.
Narlikar, J.V. and Subramanian, K. (1983). Ap. J. 273, 44 (Paper II).
Rudermann, M.A. and Spiegel, E.A. (1971). Ap. J. 165, 1.
Strittmatter, P.S. (1967). Work cited in Quasi-stellar Objects by G.R. Burbidge and E.M. Burbidge, pp. 164-174. San Francisco: W.H. Freeman and Company.
Terrell, J. (1964). Science 145, 918.
Tifft, W.J. (1987). Quantization in redshifts. In New Ideas in Astronomy (Chip Arp's Sixtieth Birthday Symposium Proceedings) ed. F. Bertola, J. Sulentic and B. Madore. Cambridge: Cambridge University Press.

Paper I.

In the Introduction the attitude of the authors to the ends of world lines is not made clear and seems ambivalent. On the one hand, singularities are regarded as reprehensible because they lead to the ending of the world lines of particles and the C-field is considered justified because it avoids such ends. On the other hand, the C-field is then introduced as arising from precisely the very "ends" that it has been claimed could be eliminated.

Page 3: I am not quite happy about the notation, a labels to the world line and also, in Equation (1), proper time, but the proper time of Equation (1) by definition and the structure of the quadratic form need not lie along world line a. This seems to be confusing. Less confusing, but still not ideal, is the use of capital A's for typical points along world lines, as well as (page 5) for a vector potential.

Page 7: f should be stated to be constant.

Page 12: Politeness is not part of science. If a number of authors have claimed something that is incorrect, however, references to these mistakes should be given.

Paper II.

I wonder whether some of the heavy calculations had better be put into an appendix.

Paper III.

I rather object to the title. Of course, the authors' theory is highly original, but it does in many cases of importance reduce to general relativity, while the title suggests to me at least an alternative to general relativity. Perhaps the authors could think of something a little different. In the Abstract I feel that the last sentence on the front page is a little arch.

In the Introduction, particularly towards the end, surely it is desirable to use the well-known term, Mach's principle. After all, the authors are attempting to satisfy this very important principle in a way not done before.

Page 21: I rather object to the authors' statement of the first requirement as being the so-called crucial tests of general relativity. The first requirement must be the derivation of Newtonian equations, and the next requirement, a little more refined, is to meet the tests distinguishing general relativity from Newtonian theory.