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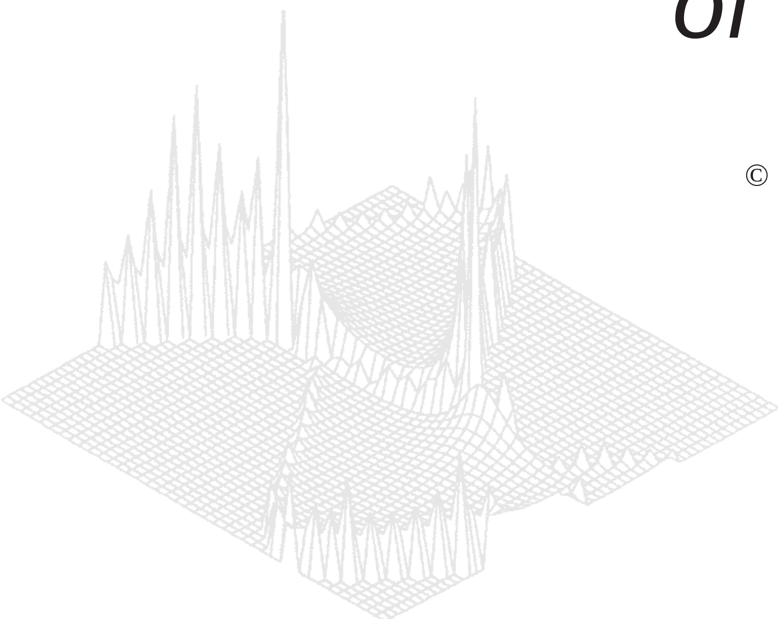

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Curvature Pressure in a Cosmology with a Tired-light Redshift

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Abstract

A hypothesis is presented that electromagnetic forces that prevent ions from following geodesics result in a curvature pressure that is very important in astrophysics. It may partly explain the solar neutrino deficiency and it may be the engine that drives astrophysical jets. However, the most important consequence is that, under general relativity without a cosmological constant, it leads to a static and stable cosmology. Combining an earlier hypothesis of a gravitational interaction of photons and particles with curved spacetime, a static cosmology is developed that predicts a Hubble constant of $H = 60{\cdot}2\,\mathrm{km\,s^{-1}Mpc^{-1}}$ and a microwave background radiation with a temperature of $3{\cdot}0\,\mathrm{K}$. The background X-ray radiation is explained, and observations of the quasar luminosity function and the angular distribution of radio sources have a better fit with this cosmology than they do with standard big-bang models. Although recent results (Pahre *et al*. 1996) for the Tolman surface brightness test favour the standard big-bang cosmology, they are not completely inconsistent with a static tired-light model. Most observations that imply the existence of dark matter measure redshift, interpret them as velocities, and invoke the virial theorem to predict masses that are much greater than those deduced from luminosities. If, however, most of these redshifts are due to the gravitational interaction in intervening clouds, no dark matter is required. Observations of quasar absorption lines, a microwave background temperature at a redshift of $z = 1{\cdot}9731$, type 1a supernovae light curves and the Butcher–Oemler effect are discussed. The evidence is not strong enough to completely eliminate a non-evolving cosmology. The result is a static and stable cosmological model that agrees with most of the current observations.

1. Introduction

North (1995) provided an excellent history of the discovery that distant galaxies had a distance-dependent redshift and of the various theories that were proposed to explain this redshift. Although there was strong initial support for tired-light models, the lack of a viable physical explanation and the apparent success of the expansion cosmology has meant that there has been little consideration of tired-light models in the last forty years. However, in a short note Grote Reber (1982) argued that Hubble himself was never a promoter of the expanding universe model and personally thought that a tired-light model was simpler and less irrational. LaViolette (1986) has compared the generic tired-light model with the big-bang model on four kinds of cosmological tests. He concluded that a non-evolving Euclidean tired-light model is a better fit for the cosmological tests of angular diameter versus redshift, magnitude versus redshift, number density

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of galaxies versus magnitude, and number density of radios sources versus flux density. He also provides references to earlier theories and to his own model for a tired-light mechanism.

The strongest theoretical arguments against a tired-light model are that it requires new physics and that any scattering mechanism that gives rise to an energy loss will also produce an angular scattering that is not observed. In the tired-light model considered here, the new physics for the redshift is minimal and the angular scattering is insignificant. In previous papers (Crawford 1987*a*, 1991) it was argued that there is a gravitational interaction such that photons and particles lose energy as they pass through a gas. The energy loss for photons results in a redshift that could produce the Hubble redshift. The argument is that photons can be treated as discrete entities with a finite extent that are subject to the 'focussing' theorem of curved spacetime. That is, the cross section of a bundle of geodesics (in a space with positive curvature) will decrease in area with distance. This is just the analogue of the convergence of lines of longitude. The hypothesis (Crawford 1987*a*) is that this focusing produces an interaction that leads to the loss of energy to very low energy secondary photons, and an effective redshift of the primary photon. Because the interaction is effectively with the mass that produces the curved spacetime, and because this mass will have a very much larger inertia than the particle, the angular scattering of the photon will be negligible.

If the Hubble redshift is explained by a non-expansion mechanism, there is still the problem that a static cosmological solution to the equations of general relativity is unstable so that a viable cosmology requires some way to provide stability. This problem was investigated (Crawford 1993) without curvature pressure in a static cosmology within a Newtonian context. That work is superseded by the present paper, which shows that, under general relativity, the use of curvature pressure can provide a static and stable cosmology. The solution is the new concept of curvature pressure, which is based on the observation that in plasmas electromagnetic forces completely dominate the particle motions so that the particles do not travel along geodesics. The curvature pressure is the reaction back on the material that generates curved spacetime from the non-geodesic motion of its component particles. Where curved spacetime is due to a plasma, the reaction is seen as a (curvature) pressure within the plasma that depends on its density and temperature and acts to prevent compression.

The curvature pressure is investigated in a static cosmological model and for plasmas that occur in the centre of the sun and around compact objects. It is shown that the effect of curvature pressure will decrease the central solar temperature by an amount that may be sufficient to explain the observed deficiency of solar neutrinos. Since curvature pressure acts to oppose contraction and since it increases with temperature, it is unlikely that black holes could form from hot plasmas. However, it remains possible to form black holes from cold material. More significantly, curvature pressure is very important in accretion disks around compact objects and may provide the engine that drives astrophysical jets.

Since the big-bang cosmological model in all its ramifications is so well entrenched, in order to be taken seriously any alternative model must at least be able to explain the major cosmological observations. It is argued that, using the Friedmann equations, the introduction of curvature pressure leads to a static and stable cosmological model. One of the predictions of this model is that there is a background X-ray radiation, and an analysis of the background observations done in a previous paper used to determine the average density of the universe. Because of its essential importance to this static cosmology and because the earlier results did not include the effects of curvature pressure, the hypothesis of a gravitational interaction is revisited. The result is a prediction of the Hubble constant $H = 60 \cdot 2$ km^{-1} Mpc^{-1} and the existence of the microwave background radiation with a temperature of $3 \cdot 0$ K. It is shown how the observations that lead to the postulate of dark matter in the big-bang cosmology are readily explained without dark matter. Next, previous work on the luminosity function of quasars and the angular sizes of radio sources is discussed to show that the observations can be fitted without evolution. The classic Tolman surface brightness test is discussed with respect to recent observations from Pahre *et al.* (1996). The theme of evolution, or lack of it, is continued with an examination of observations on quasar absorption lines, a microwave background temperature at high redshift, type 1a supernovae light curves and the Butcher–Oemler effect. Finally the topics of nuclear abundance, entropy and Olber's paradox are briefly covered.

2. Theoretical Background

A theme that is common to the development of both curvature pressure and the gravitational interaction is that in four-dimensional space the effects of centripetal acceleration are essentially the same as they are in three-dimensional-space. Mathematically, a smooth three-dimensional curved space can be locally approximated as a four-dimensional Euclidean space. Provided that the volume is small enough and the curvature is smooth enough, higher-order spaces can be neglected. The hypothesis made here is that this four-dimensional space has a physical reality. Note that this is not to be confused with four-dimensional spacetime; here we have five-dimensional spacetime. Consider two meridians of longitude at the equator with a perpendicular separation of h; then as we move along the longitudes this separation obeys the differential equation $h'' = -h/r^2$, where the primes denote differentiation with respect to the path length and r is the radius of the Earth. In addition, the particle has a centripetal acceleration of v^2/r, where r can be determined from the behaviour of h''. In four-dimensional space the longitudes become a geodesic bundle and the separation becomes a cross-sectional area, A, where $A'' = -A/r^2$. Again the particle has a centripetal acceleration of v^2/r, where now r is the radius of the hypersphere. Although the particle as we know it is confined to three dimensions, there is a centripetal acceleration due to curvature in the fourth dimension that could have significant effects. Another fundamental topic considered is the nature of gravitational force. It is critical to the development of curvature pressure that gravitation produces accelerations and not forces.

The gravitational interaction theory explicitly requires that photons and particles be described by localised wave packets. The wave equations that describe their motion in flat spacetime are carried over to curved spacetime in which the rays coincide with geodesics. In particular, in the focusing theorem (Misner *et al.* 1973) there is an actual focusing of the wave packet, in that its cross-sectional area decreases as the particle (photon) travels along its trajectory. In this and previous papers (Crawford 1987*a*, 1991) it is argued that the result is a gravitational interaction in which the particle loses energy.

3. Theoretical Model for Curvature Pressure

In a plasma there are strong, long-range electromagnetic forces that completely dominate accelerations due to gravitational curvature. The result is that, especially for electrons, the particles do not travel along geodesics. If we stand on the surface of the Earth, our natural geodesic is one of free fall but the contact forces of the ground balance the gravitational acceleration, with the consequence that there is a reaction force back on the ground. The result of stopping our geodesic motion is to produce a force that compresses the ground. The major hypothesis of this paper is that there is a similar reaction force in four-dimensional spacetime. This force acts back on the plasma (that produces the curved spacetime) because its particles do not follow geodesics. Thus the plasma appears in two roles. The first produces the curved spacetime, and in the second the failure of its particles to follow geodesics causes a reaction back on itself acting in the first role. It is long-range electromagnetic forces that are important, not particle collisions. For example, in a gas without long-range forces, and assuming that the time spent during collisions is negligible, the particles will still travel along geodesics between collisions. Given that there are long-range forces that dominate the particle trajectories, there is a reaction force that appears as a pressure, the curvature pressure.

For the cosmological model, consider the plasma to occupy the surface of a four-dimensional hypersphere. It is easier to imagine this if one of the normal dimensions is suppressed; it will then appear as the two-dimensional surface of a three-dimensional sphere. The nature of this pressure can then be understood by analysing this reduced model with Newtonian physics in three-dimensional space. In this case the curvature pressure acts within the two-dimensional surface and is another way of describing the effects of the centripetal accelerations of the particles. By symmetry, the gravitational attraction on one particle due to the rest is equivalent to having the total mass at the centre of the sphere. To start, let the shell contain identical particles, all with the same velocity, and let this sphere have a radius r; then the radial acceleration of a particle with velocity v is v^2/r. At equilibrium the radial accelerations are balanced by the mutual gravitational attraction. Now for a small change in radius, dr, without any change in the particle velocities and going from one equilibrium position to another, we can equate the work done by the curvature pressure to the work done by the force required to overcome the centripetal acceleration to get

$$p_c dA = -\frac{Mv^2}{r}dr\,, \tag{1}$$

where M is the total mass, but for a two-dimensional area $dA/dr = 2A/r$, therefore $p_c = -Mv^2/2Ar = -\rho v^2/2$, where ρ is the surface density. Thus the effects of the centripetal accelerations can be represented as a negative pressure acting within the shell. The next step is to generalise this result to many types of particles, where each type of particle has a distribution of velocities.

The particles are constrained to stay in the shell by a dimensional constraint that is not a force. The experiments of Eötvös and others (Roll *et al.* 1964; Braginski and Panov 1971) show that the Newtonian passive gravitational mass is identical to the inertial mass to about one part in 10^{12}. The logical conclusion is that Newtonian gravitation produces an acceleration and not a force. The mass is only introduced for consistency with Newton's second law of motion. The concept of gravitation as an acceleration and not a force is even stronger in general relativity. Here the geodesics are the same for all particles independent of their mass, and gravitational motion does not use the concept of force. Clearly for a single type of particle the averaging over velocities is straightforward, so that the curvature pressure is $p_c = -\rho\overline{v^2}/2$. The averaging over particles with different masses is more ambiguous. Traditionally we would weight the squared velocities by their masses; that is, we compute the average energy. However, since the constraint that holds the particles within the two-dimensional shell is not due to forces and since gravitation produces accelerations and not forces, the appropriate average is over their accelerations. The result for our simple Newtonian model is

$$p_c = -\tfrac{1}{2}\rho\sum_i \overline{v_i^2}\,, \tag{2}$$

where the density is defined as $\rho = \sum\limits_i n_i m_i$ and n_i is the number density of the ith type of particle. This simple Newtonian model gives a guide to what the curvature pressure would be for a more general model in a homogeneous, isotropic three-dimensional gas that forms the surface of a four-dimensional hypersphere. The dimensional change requires that we replace dA/dr by $dV/dr = V/3r$, and then including the relativistic corrections (a factor of γ^2) needed to transform the accelerations from the particle's reference system to a common system where the average velocity is zero, we get

$$\begin{aligned} p_c &= -\frac{\rho}{3}\sum_i n_i\overline{\gamma_i^2 v_i^2} \\ &= -\frac{\rho c^2}{3}\sum_i n_i\left(\overline{\gamma_i^2}-1\right) \\ &= -\frac{\rho c^2}{3}\left(\overline{\gamma^2}-1\right), \end{aligned} \tag{3}$$

where the Lorentz factor $\gamma^2 = 1/\sqrt{1-v^2/c^2}$. Note that although the equation for curvature pressure does not explicitly include the spacetime curvature, the derivation requires that it is not zero. Because this equation was only obtained by a plausibility argument, we hypothesise that the curvature pressure in the cosmological model is given by equation (3).

Since the particles may have relativistic velocities, and assuming thermodynamic equilibrium, the $(\overline{\gamma^2}-1)$ factor can be evaluated using the Jüttner distribution. For a gas at temperature T and particles with mass m, de Groot *et al.* (1980) showed that

$$\gamma^2(\alpha) = 3\alpha K_3(1/\alpha)/K_2(1/\alpha) + 1\,, \tag{4}$$

where $\alpha = kT/mc^2$ and $K_n(1/\alpha)$ are the modified Bessel functions of the second kind (Abramowitz and Stegun 1968). For small α this has the approximation

$$\gamma^2(\alpha) = 1 + 3\alpha + 152\alpha^2 + 458\alpha^3 + \ldots. \tag{5}$$

Note that for a Maxwellian distribution the first three terms are exact so that the extra terms are corrections required for the Jüttner distribution. For non-relativistic velocities equation (5) can be used and equation (3) becomes

$$p_c = -\frac{1}{N}\sum_{i=1}^{N}\left(\frac{n_i}{m_i}\right)\overline{m}kT\,, \tag{6}$$

where n_i is the number density for the ith type of particle and $\overline{m} = \sum_{i=1}^{N} n_i m_i/n$ is the mean particle mass. Except for the inverse mass weighting and the sign, this is identical to the expression for the thermodynamic pressure.

4. Solar Interior and Local Plasma Concentrations

The equation for curvature pressure derived above for the cosmological model cannot be used in other situations with different metrics. The key to understanding the application of curvature pressure in other metrics, such as the Schwartzschild metric used for stellar interiors, is to consider the case where the overall curvature is small and superposition may be assumed. Since the free-fall acceleration of a particle is independent of its mass, there is no curvature pressure associated with external gravitational fields, provided that they have scale lengths much greater than the typical ion separation. Any curvature pressure is due to local curvature of the metric produced by the local density. This arises because although the electrons and ions have in general different centripetal accelerations, these are completely dominated by accelerations due to the electromagnetic forces. Let the gravitational potential be Φ, then the self-gravitational energy density is $\rho\Phi$. Now it was argued above that the curvature pressure is proportional to the energy density (it has the same units) but with an averaging over accelerations rather than forces this results in replacing ρ by $(\overline{\gamma^2} - 1)\rho$. Consequently we take the curvature pressure in a plasma due to its own density as

$$p_c = \tfrac{1}{3}(\overline{\gamma^2} - 1)\rho\Phi\,. \tag{7}$$

Note that the derivation is essentially one based on dimensional analysis and therefore the numerical factor of $\frac{1}{3}$ may need modification. It was used in part for consistency with the cosmological curvature pressure and in part because it makes the application of equation (7) to a low-temperature gas with a single type of particle have the simple expression $p_c = p_T\Phi/c^2$, where p_T is the thermodynamic pressure. From potential theory we get for the curvature pressure of a plasma at the point r_0 the expression

$$p_c(r_0) = \tfrac{1}{3} G\rho(r_0)(\overline{\gamma^2(r_0)} - 1) \int \frac{\rho(r - r_0)}{|r - r_0|} dV.$$

Equation (8) can be simplified for non-relativistic velocities by using the approximation (equation 5) to get

$$p_c = \frac{G\rho\,(r_0)\,kT}{c^2} \left(\sum_{i=1}^{N} \frac{n_i}{nm_i} \right) \int \frac{\rho\,(r - r_0)}{|r - r_0|} dV\,, \tag{9}$$

where n is the total number density.

The curvature pressure adds to the thermodynamic pressure (and radiation pressure) to support the solar atmosphere against its own gravitational attraction. That is, for the same gravitational attraction the required thermodynamic pressure, and hence the temperature, will be reduced by curvature pressure. Applying equation (9) to the sun and using pressures, temperatures, and abundance ratios given by Bahcall (1989), it was found that the curvature pressure at the centre of the sun is $2{\cdot}8 \times 10^{14}$ Pa compared to the thermodynamic pressure of $2{\cdot}3 \times 10^{16}$ Pa. Since the temperature is directly proportional to the thermodynamic pressure, this implies that the temperature at the centre of the sun is reduced by $1{\cdot}2$%. Bahcall (1989, p. 151) shows that the ^{8}B neutrino flux is very sensitive to the temperatures at the centre of the sun, with a flux rate that is proportional to the eighteenth power of the temperature. Thus this temperature change would decrease the neutrino flux to 80% of that from the standard model. Although the observed ratio of $2{\cdot}55/9{\cdot}5 = 27\%$ (Bahcall 1997) is much smaller, the effect of the curvature pressure is clearly significant and large enough to warrant a more sophisticated computation.

5. Cosmology with Curvature Pressure

The main application of curvature pressure is to a cosmological model for a homogeneous and isotropic distribution of a fully ionised gas. Based on the theory of general relativity and using the Robertson–Walker metric, the Friedmann equations (Weinberg 1972) are

$$-\ddot{R} = \frac{4\pi G}{c^2} \left(\rho c^2 + 3p \right) R,$$

$$R\ddot{R} + 2\dot{R}^2 = \frac{4\pi G}{c^2} \left(\rho c^2 - p \right) R^2 - 2kc^2,$$

where R is the radius, ρ is the proper density, p is the pressure, G is the Newtonian gravitational constant, and c is the velocity of light. The constant k is 1 for a closed universe, -1 for an open universe and zero for a universe with zero curvature. Working to order m_e/m_H, the thermodynamic pressure can be neglected but not the curvature pressure. The equations including the curvature pressure (equation 3) are

$$-\ddot{R} = 4\pi G\rho R\{1 - (\overline{\gamma^2} - 1)\},$$

$$R\ddot{R} + 2\dot{R}^2 = 4\pi G\rho R^2\{1 + \tfrac{1}{3}(\overline{\gamma^2} - 1)\} - 2kc^2,$$

where $\overline{\gamma^2}$ is the average over all velocities and particle types. Clearly $\ddot{R}$ is zero if $\overline{\gamma^2} = 2$ and equation (4) can be solved for a hydrogen plasma to get $\alpha_e = kT_0/m_e c^2 = 0{\cdot}335$ or $T_0 = 1{\cdot}99 \times 10^9\,\mathrm{K}$. Thus with thermal equilibrium the second derivative of R is zero if the plasma has this temperature. Hence the requirement for stability leads to a prediction of the plasma temperature. This temperature is based on a model in which the plasma is homogeneous, but the occurrence of galaxies and clusters of galaxies shows that it is far from homogeneous. In order to investigate the effects of inhomogeneity, consider a simple and quite arbitrary model where the plasma is clumped, with the probability of a clump having the density n given by the exponential distribution $\exp(-n/n_0)/n_0$, where $n_0 n$ is the average density. Assuming pressure equilibrium so that $T_e = T_0 n_0/n$ then for $\overline{\gamma^2} = 2$ we find that the average temperature $T = 1{\cdot}1 \times 10^9$ K, thus showing that the effect of inhomogeneity could reduce the observed temperature by a factor of order 2.

Since the right-hand side of the second Friedmann equation is positive, the curvature constant k must be greater than or equal to zero. The only useful static solution requires that $k = 1$, and with $\dot{R} = \ddot{R} = 0$ the result for the radius of the universe is

$$\frac{1}{R_0^2} = \frac{8\pi G\rho_0}{3c^2}.$$

Thus the model is a static cosmology with positive curvature. Although the geometry is the same as that of the original Einstein static model, this cosmology differs in that it does not require a cosmological constant. Furthermore it is stable. Consider a perturbation, ΔR, about the equilibrium position. Then the perturbation equation is

$$\Delta\ddot{R} = \frac{c^2}{8\pi R_0}\left(\frac{d\overline{\gamma^2}}{dR}\right)\Delta R\,, \tag{11}$$

and since for any realistic equation of state the average velocity (temperature) will decrease as R increases, the right-hand side is negative, showing that the result of a perturbation is an oscillation about the equilibrium value. Thus this model does not suffer from the deficiency that the static Einstein model has of gross instability. Since the volume of the three-dimensional surface of the hypersphere is $2\pi^2 R_0^3$, the radius of the universe can be written in terms of the total mass of the universe, M_0, as

$$R_0 = \frac{4GM_0}{3\pi c^2}\,, \tag{12}$$

which differs by a factor of $\frac{2}{3}$ from that which was derived from a purely Newtonian model (Crawford 1993). For interest the values with a density of $2\cdot05 m_H$ m^{-3} (see below) are $R_0 = 2\cdot17 \times 10^{26}$ m $= 7\cdot04$ Gpc, and $M_0 = 6\cdot90 \times 10^{53}$ kg $= 3\cdot47 \times 10^{23}\,M_\odot$.

6. Background X-ray Radiation

If this cosmological model is correct there should be a very hot plasma between the galaxies and, in particular, between galactic clusters. This plasma should produce a diffuse background X-ray radiation and indeed such radiation is observed. Attempts to explain the X-rays in terms of bremsstrahlung radiation within the standard model have not been very successful (Fabian and Barcons 1992), mainly because they must have originated at earlier epochs when the density was considerably larger than at present. The hard X-rays could come from discrete sources but if they did there are problems with the spectral smoothness, and strong evolution is required to achieve the observed flux density (Fabian and Barcons 1992). However, there is an excellent fit to the data in a static cosmology (Crawford 1987*b*, 1993) for X-ray energies between 5 keV and 200 keV. Using universal abundances (Allen 1976), the analysis showed a temperature of $1\cdot11 \times 10^9$ K and a density of $2\cdot05 m_H$ m^{-3}. Comparison of this temperature with that predicted by the homogeneous model of 171 keV shows that it is nearly a factor of 2 too small. A possible explanation comes from the observation that the universe is not homogeneous. Although there is fortuitous agreement with the simple inhomogeneous model described above, this can only be interpreted as showing that the observations are consistent with an inhomogeneous model.

One of the main arguments against the explanation that the background X-ray radiation comes from a hot intercluster plasma is that this plasma would distort the cosmic microwave background radiation by the Sunyaev–Zel'dovich effect. This distortion is usually expressed by the dimensionless parameter y. Mather *et al*. (1994) measured the spectrum of the cosmic microwave background radiation and conclude, that $|y| < 2\cdot5 \times 10^{-5}$. In the big-bang cosmology most of the distortion occurs at earlier epochs, where the predicted density and the temperature of the plasma are much higher than current values. However, for any static model we can use a constant density of $2\cdot05 m_H$ m^{-3} in the equation (Peebles 1993)

$$y = \frac{kT_e \sigma_T n_e r}{m_e c^2}\,, \tag{13}$$

where σ_T is the Thomson cross section and r is the pathlength since the formation of the radiation. For a hydrogen plasma we get $y = 2\cdot6 \times 10^{-29} r$. The microwave background radiation (see below) is being continuously replenished by energy losses from the hot electrons and the typical path length for the energy lost by electrons to equal the energy of a photon at the peak of the spectrum is $3{\cdot}5\times10^{18}\,$m, which results in $y=9{\cdot}1\times10^{-11}$, well within the observed limits.

7. The Hubble Constant

One of the major requirements of any cosmological model is the necessity to explain the relationship found by Hubble that the redshift of extragalactic objects depends on their distance. In earlier papers (Crawford 1987*a*, 1991) the author suggested that there is an interaction of photons with curved spacetime that produces an energy loss that can explain the Hubble redshift relationship. Because the earlier work did not include the effects of curvature pressure, and because this interaction is central to the description of a viable static cosmology, a brief updated description is given here. The principle is that a photon can be considered as a localised wave travelling along a geodesic bundle. Because of the 'focusing theorem' (Misner *et al.* 1973) the cross-sectional area of this bundle will decrease with time, and in applying this theorem to a photon it was argued that this will cause a change in the photon's properties. In particular, angular momentum will decrease because it is proportional to a spatial integral over the cross-sectional area. The change in angular momentum can only be sustained for a time consistent with the Heisenberg uncertainty principle. The conclusion is that eventually two (in order to conserve the total angular momentum) very low-energy photons will be emitted.

The second part of the argument is that the rate at which this energy loss occurs is proportional to the rate of change of area of the geodesic bundle. This rate of change of area, in the absence of shear and vorticity, is given by the equation (Raychaudhuri 1955)

$$\frac{1}{A}\frac{d^2A}{ds^2}=-R_{\alpha\beta}U^\alpha U^\beta\,, \tag{14}$$

where $R_{\alpha\beta}$ is the Ricci tensor, U^α is the four-velocity and s is a suitable affine parameter. At any point the trajectory of the geodesic bundle is tangential to the surface of a four-dimensional hypersphere with radius r. Then since the centripetal acceleration is c^2/r, where r is defined by

$$\frac{1}{r^2}=\frac{1}{A}\frac{d^2A}{ds^2}\,, \tag{15}$$

we can define ε, the fractional rate of energy loss, by

$$\varepsilon=c^2\sqrt{\frac{1}{A}\frac{d^2A}{ds^2}}\,. \tag{16}$$

This relationship for ε is a function only of Riemann geometry and does not depend on any particular gravitational theory. However, Einstein's general relativity gives a particularly elegant evaluation. Direct application of the field equations with the stress–energy–momentum tensor $T_{\alpha\beta}$ gives

$$\varepsilon = \sqrt{\frac{8\pi G}{c^2}\left(T_{\alpha\beta}U^\alpha U^\beta - \tfrac{1}{2}T g_{\alpha\beta}U^\alpha U^\beta\right)}\,, \tag{17}$$

where T is the contraction of $T_{\alpha\beta}$ and U^α is the four-velocity. Then for a gas with density ρ where the pressures are negligible, the energy loss rate is (Crawford 1987*a*)

$$\varepsilon c = -\frac{1}{E}\frac{dE}{dt} = \sqrt{\frac{8\pi G\left(\rho c^2 + p\right)}{c^2}}\,, \tag{18}$$

where x is measured along the photon's trajectory. This equation can be integrated to obtain

$$E = E_0 \exp(-\varepsilon x)\,. \tag{19}$$

If $\rho = n\, m_H$ and with (using equation 3)

$$p \approx p_c = -\frac{\rho c^2}{3}(\overline{\gamma^2} - 1) = -\tfrac{1}{3}\rho c^2\,, \tag{20}$$

then $\varepsilon = 4\cdot 54\times 10^{-27}\sqrt{n}\,\mathrm{m}^{-1}$ and the predicted Hubble constant is

$$H = c\varepsilon = 42\cdot 0\,\sqrt{n}\,\mathrm{km\ s^{-1}\ Mpc^{-1}}\,. \tag{21}$$

With the value $n = 2\cdot 05 m_H \mathrm{m}^{-3}$ we get $H = 60\cdot 2\ \mathrm{km\ s^{-1}\,Mpc^{-1}}$. Note that for non-cosmological applications where the curvature pressure is negligible, the results are $\varepsilon = 5\cdot 57\times 10^{-27}\sqrt{n}\,\mathrm{m}^{-1}$ or

$$\varepsilon c = 51\cdot 5\sqrt{n}\,\mathrm{km\ s^{-1}\ Mpc^{-1}}\,. \tag{22}$$

We will require later the product of Hubble's constant with the radius of the universe, which is $RH = \sqrt{2}\,c$. This is identical to the value derived earlier (Crawford 1993) for a Newtonian cosmology.

The principle of the focusing theorem can be illustrated by considering a very long cylinder of gas under Newtonian gravitation. At the edge of the cylinder of radius r the acceleration towards the centre of the cylinder is $\ddot{r} = 2\pi G\rho r$, where the dots denote differentiation with respect to time. Hence for the area A we get $\ddot{A} = 4\pi G\rho A$. Except for the numerical constant this is the same as that for general relativity, showing that it is the local density that determines focusing. The difference of a factor of $\frac{1}{2}$ arises because the model only includes space curvature and not spacetime curvature. In both cases distant masses have no effect. In particular, there is no focusing and hence no energy loss in the exterior Schwartzschild field of a spherical mass distribution such as the sun.

Since the excitation of the photon is slowly built up along its trajectory before the emission of two low-energy photons, any other interaction that occurs with a pathlength shorter than that between the emission of secondaries will clearly diminish their production. That is, the excitation can be dissipated without any extra energy loss. The average distance between emission, of secondaries is (Crawford 1987*a*; using Heisenberg's uncertainty principle) $\Delta x = \sqrt{\lambda_0/4\pi\varepsilon}$, where h is Planck's constant, ε is the fractional rate of energy loss per unit distance defined above, and λ_0 is the wavelength of the primary photon. For the cosmological plasma the secondaries would have a typical frequency of $0\cdot02$ Hz for a 21 cm primary and about 11 Hz for an optical photon, which may be compared with the plasma frequency of 13 Hz. Thus in most cases the secondaries will not propagate but will be directly absorbed by the plasma.

The classic experiment of Pound and Snider (1965) is an example of how the hypothesis of a gravitational interaction may be tested. They used the Mössbauer effect to measure the energy of $14\cdot4\,\mathrm{keV}$ (^{57}Co) gamma rays after they had passed up or down a $22\cdot5\,\mathrm{m}$ path in helium. Their result for the gravitational redshift was in excellent agreement with the predicted fractional change in energy of $2\cdot5\times10^{-15}$. The gravitational interaction theory predicts a fractional change in energy due to the gravitational interaction based on the density of helium in the tube of $1\cdot25\times10^{-12}$, which is considerably larger. Since Pound and Snider's measurement was for the difference between upward and downward paths any effects independent of direction will cancel. However, for these conditions, although the typical path length between the emission of secondaries of 11 m is less than the length of the apparatus, it is still much longer than the mean free path for coherent forward scattering, that is, the quantum description of refractive index. In this scattering the photon is absorbed by many electrons and after a short time delay (half a period) a new photon with the same energy and momentum is emitted. For these high-energy gamma rays the binding energy of the electrons can be ignored and the mean free path for coherent forward scattering is given by the Ewald and Oseen extinction length (Jackson 1975) of $X = 1/\lambda r_0 n_e$, where λ is the wavelength and r_0 is the classical electron radius. In this case $X = 0\cdot15\,\mathrm{m}$, that is, much less than the 11 m required for secondary emission, and therefore the gravitational interaction energy loss will be minimal. The major difficulty with a laboratory test is in devising an experiment where Δx is less than the size of the apparatus and also less than the mean free path of any other interaction. Nevertheless, if there are any residual effects they may be detectable in such an experiment with a horizontal run using gases of different types and densities.

This inhibition of the gravitational interaction can occur in astrophysical situations. Consider the propagation of radiation through the Galaxy where there is a fully ionized plasma with density $\rho = n\,m_H$. Then the critical density occurs when the Ewald and Oseen extinction length is equal to the distance between emissions of secondary photons. If the density is greater than this critical density, then the inhibition by refractive index impairs the gravitational interaction and there is a greatly reduced redshift. The critical density (for a hydrogen plasma) is $n_e = 426\cdot5/\lambda^2\,\mathrm{m}^{-3}$. For 21 cm radiation the critical density is $n_e = 9700\,\mathrm{m}^{-3}$ and since most interstellar densities are much larger than this, we do not expect 21 cm radiation within the Galaxy to show redshifts due to the gravitational interaction. However, if the gas is very clumpy we could still get uninhibited redshifts from the low-density components. Thus all redshifts of 21 cm radiation within the Galaxy may be primarily due to Doppler shifts. However, optical radiation in the Galaxy should show the redshift due to the gravitational interaction. This inhibition could be verified if a neutral hydrogen cloud could be clearly identified with an object having optical line emission.

It has been argued (Zel'dovich 1963) that tired-light cosmologies (such as this) should show a smearing out of the images of distant sources. The argument is that if the energy loss is caused by an interaction with intergalactic matter, it is accompanied by a transfer of momentum with a corresponding change in direction. That is, the photon is subject to multiple scattering and hence photons from the same source will eventually have slightly different directions and the source's image will be smeared. For the gravitational interaction, the interaction is not with some particle with commensurate mass but with the mass of the gas averaged over a suitable volume. Since the effective mass is so large the scattering angles will be negligible. Furthermore, in low, density gas the photon loses energy to two secondary photons, and to conserve spin and momentum these will on average be emitted symmetrically so that there is no scattering of the primary photon. Thus this model overcomes the scattering objection to tired-light explanations for redshifts.

8. The Microwave Background Radiation

Because of their wave nature, electrons and other particles will be subject to the focusing theorem in a way similar to photons. Crawford (1991) argued that particles such as electrons are subject to a similar centripetal acceleration that produces a fractional energy loss rate of ε_e, and for a gas with density ρ and pressure p it is

$$\varepsilon_e = \sqrt{\frac{8\pi G}{c^2}[(\gamma^2 - \tfrac{1}{2})\rho c^2 + (\gamma^2 + \tfrac{1}{2})p]}\,, \tag{23}$$

where γ is the usual velocity factor. Hence the rate of energy loss as a function of distance is

$$\frac{dP^0}{dx} = \sqrt{\frac{8\pi G}{c^4}[(\gamma^2 - \tfrac{1}{2})\rho c^2 + (\gamma^2 + \tfrac{1}{2})p]\beta^2 P^0}\,, \tag{24}$$

where $\beta = v/c$ is the particle's velocity relative to the medium and P^0 is the energy component of its momentum four-vector. As it moves along its trajectory, the particle will be excited by the focusing of its wave packet. For charged particles, conservation of spin prevents them from removing their excitation by direct emission of low-energy photons. However, if there are photons present they may interact by stimulated emission and thereby lose energy to secondary photons. The dominant photon field in intergalactic space is that associated with the microwave background radiation. The model proposed is that the electrons lose energy by stimulated emission to the background radiation so that the local black-body spectrum is conserved. Since the conservation of energy, momentum and spin prevents a free electron from radiating, it can only lose its energy of excitation by interacting with another particle or in this case the radiation field. The hypothesis is that it continuously gains energy until an interaction with a photon stimulates the emission of a new photon. Thus the energy spectrum of the emitted photons will match that of the existing photons. Thus given a local black-body spectrum, the emitted radiation will also have the same black-body spectrum. This does not explain how the black body radiation originally arose but if there is any way in which photons can interact to alter their energy spectrum, then the equilibrium spectrum is that for a black body.

Concurrently, because of the gravitational interaction the photons are losing energy that is absorbed by the plasma. Note that most of the secondary photons have frequencies below the plasma frequency. Although this means that they cannot propagate, it does not prevent direct absorption of their energy. After all, for frequencies below the plasma frequency the electrons can have bulk motion and absorb energy from an oscillating field. Given an equilibrium condition in which the energy lost by the electrons is equal to the energy lost by the photons we can equate the two energy loss rates and get an expression for the temperature of the microwave background radiation (Crawford 1991)

$$T_M^4 = \frac{n_e m_e c^3}{4\sigma}\overline{\left((\gamma^2 - \tfrac{1}{2}) + (\gamma^2 + \tfrac{1}{2})\frac{p}{\rho c^2}\right)\beta^3\gamma}\,, \qquad (25)$$

where n_e is the electron number density, m_e is the electron mass, σ is the Stefan–Boltzmann constant and an average is done over all electron velocities. For an electron temperature of $1{\cdot}11 \times 10^9$ K the bracketed term has the value of $0{\cdot}555$ with zero pressure or $0{\cdot}412$ with the gravitational curvature pressure. With an electron density of $1{\cdot}78\,\mathrm{m}^{-3}$, corresponding to a mass density of $2{\cdot}05 m_H \mathrm{m}^{-3}$, and with the curvature pressure included, the predicted temperature is $3{\cdot}0$ K. Given the deficiencies of the model (mainly its assumption of homogeneity), this is in good agreement with the observed value of $2{\cdot}726$ K (Mather *et al.* 1994). It is interesting that the predicted temperature depends only on the average density and a function of electron velocities that is of order 1.

9. Dark Matter

In the standard big-bang cosmology there are three major arguments (Trimble 1987) for the existence of dark matter, that is, matter that has gravitational importance but is not seen at any wavelength. The first argument is based on theoretical considerations of closure and reasonable cosmological models within the big-bang paradigm. The second is from the application of the virial theorem to clusters of galaxies, and the third is that galactic rotation curves show high velocities at large radii. The first of these is purely an artefact of the big-bang cosmological model; it is not based on observation and therefore it is not relevant to this cosmology. The second and third are based on observations and will be discussed at some length.

In the standard big-bang model all the galaxies in a cluster are gravitationally bound and do not partake in the universal expansion. If they are gravitationally bound, then assuming that their differential (peculiar) redshifts are due to differential velocities, we can use the virial theorem to estimate the total (gravitational) mass in the cluster. Typically this gravitational mass is one to several orders of magnitude larger than the mass derived from the luminosities of the galaxies, hence the need for dark matter.

Observations of X-rays from galactic clusters show that there is a large mass of gas in the space between the galaxies. Although the mass of this intercluster gas is small compared to the mass of the presumed dark matter, it is large enough to give significant redshifts due to the gravitational interaction. Thus the current model ascribes most of the differential redshifts to gravitational interactions in the intercluster gas. This model has been quantitatively investigated by Crawford (1991) for the Coma cluster. The method used was to take the observed differential redshift for each galaxy, and by integrating equation (22) through the known intergalactic gas, to compute the differential line-of-sight distance to the galaxy. The gas density distribution that was used is that given by Geller *et al*. (1979). The result is that galaxies with lower redshifts than that for the centre of the cluster would be nearer and those with higher redshifts would be further away. The model assumed that the intercluster gas was spherically distributed and the test was in how well the distribution of Z coordinates compared with those for the X and Y coordinates that were in the plane of the sky. Furthermore it was assumed that genuine velocities were negligible compared to the effective velocities of the differential redshifts. The median distances for each coordinate were $X = 0\cdot 19\,\mathrm{Mpc}$, $Y = 0\cdot 17\,\mathrm{Mpc}$ and $Z = 0\cdot 28\,\mathrm{Mpc}$. Given that the Coma cluster has non-spherical structure and that the model is very simple, the agreement of the median Z distance with those for X and Y is good. Again it should be emphasised that there were no free parameters; the Z distances depend only on the gas distribution, the measured differential redshift, and equation (22). If this result can be taken as representative of clusters, then there is no need for dark matter to explain cluster 'dynamics'. The large differential redshifts are mainly due to gravitational interactions in the intergalactic gas.

One of the difficulties with the big-bang cosmology is that it is so vague in its predictions that it is very difficult to refute it with observational evidence. However, the redshifts from a cluster of galaxies can provide a critical test. Since celestial dynamics is time-reversible, a galaxy at any point in the cluster is equally likely to have a line-of-sight velocity towards us as away from us. Then if accurate measurements of magnitude, size or some other variable can be used to get differential distances, there should (in the big-bang cosmology) be no correlation between differential redshift and distance within the cluster, whereas in the static cosmology proposed here there should be a strong correlation, with the more distant galaxies having a higher differential redshift. Clearly this is a difficult experiment since for the Coma cluster it requires measurements of differential distances to an accuracy of about $1\,\mathrm{Mpc}$ at a distance of $100\,\mathrm{Mpc}$.

The third argument for dark matter comes from galactic rotation curves. What is observed is that velocity plotted as a function of distance along the major axis shows the expected rapid rise from the centre, but instead of reaching a maximum and then declining in an approximately Keplerian manner, it tends to stay near its maximum value. The standard explanation is that there is a halo of dark matter that extends well beyond the galaxy and that has a larger mass than the visible galaxy. For this static cosmology a partial explanation is that most of the redshift is due to gravitational interaction in a halo, but one that is commensurate in size with the galaxy. Consider a spiral galaxy that is inclined to the line of sight and that has a halo with a Gaussian density distribution (chosen purely for analytic convenience). Then if the redshift origin is taken to be at the centre of the galaxy, light from points further away will travel through more halo gas and therefore will be redshifted and nearer points will be blueshifted. Let the halo density distribution as a function of radius be $\rho = \rho_0 \exp[-(r/r_0)^2]$ and let x be the distance measured from the galaxy centre along a line through the galaxy that lies in the same plane as the line of sight and the normal to the galaxy. Then the observed redshift (in velocity units) is

$$v - v_0 = \pi(4G\rho_0)^{\frac{1}{2}} r_0 \exp\left(-\left(\frac{x\sin(i)}{\sqrt{2}r_0}\right)^2\right) \operatorname{erf}\left(\frac{x\cos(i)}{\sqrt{2}r_0}\right), \qquad (26)$$

where i is the inclination angle. Since the error function is asymmetric and the exponential function dominates at large distances, the relative velocity shows a rapid increase to a broad maximum and then a slow decrease back to zero. For most galaxies it is likely that the maxima extend well beyond the physical limits of the galaxy so that only part of the decrease may be observed. Clearly the precise shape of the curve and its numerical value will depend on the precise nature of the density distribution. Nevertheless the value of the maximum velocity for this curve will give a good indication of the effect. For an inclination angle of 45° the maximum occurs when $x \simeq 0{\cdot}8 r_0$, and it has the value $1{\cdot}4 \times 10^{-2} r_0 \sqrt{n_0}$, where r_0 is in kpc and n_0 is the density in H atoms per m^3. For the values $r_0 = 10$ kpc and $n_0 = 10^6$, the maximum redshift in velocity units is $140\,\mathrm{km\,s^{-1}}$ which is within the range of observed values. The difficulty with this model is that it predicts that the maximum spectral shifts should occur along the line of sight, whereas most observations show that the maximum velocity gradient is along the major axis. Although it is possible to devise density distributions that can explain particular rotation curves, there is no universal model that can explain all rotation curves. Nevertheless the fact that it predicts the magnitude and shape of a typical galactic redshift curve must carry some weight.

If the size and shape of the halo are simple functions of the galaxy luminosity, this model can partly explain the Tully–Fisher correlation for spiral galaxies (Rowan-Robinson 1984) and the Faber–Jackson (1976) correlation for elliptical galaxies. The latter observed that the absolute magnitude of galaxies is correlated with the width of the 21-cm emission line of neutral hydrogen. If the line is primarily due to gravitational interactions in the galactic halo, then its width is $W_0 = A\pi(4G\rho_0)^{\frac{1}{2}} r_0$, where A is a constant of order unity that depends on the actual density distribution. To proceed further requires knowledge of how the halo properties depend on luminosity.

These two cases illustrate an important aspect of redshifts in this cosmology. Although the redshift is on average an excellent measure of distance, any particular redshift is only a measure of the gas in its line of sight. Any lumpiness in the intercluster gas will produce apparent structure in redshifts that could be falsely interpreted as structure in galaxy distributions. That is, the apparent 'walls', 'holes', and other structures may be due to intervening higher-density or lower-density clouds. For example, the model predicts an apparent hole behind clusters of galaxies because of gravitational interactions in intracluster gas. The velocity width of the hole would be of the same magnitude as the velocity dispersion in the cluster. For the Coma cluster the velocity width of this hole would vary from about $4100\,\mathrm{km\,s^{-1}}$ near the centre of the cluster to about $1200\,\mathrm{km\,s^{-1}}$ near the edge.

10. No Evolution

The most important observational difference between this cosmology and the big-bang cosmology is that it obeys the perfect cosmological principle: it is homogeneous both in space and time. Consequently any unequivocal evidence of evolution would be fatal to its viability. In contrast, the big-bang theory demands evolution. However, it has the difficulty that the theory only provides broad guides as to what that evolution should be, and there is little communality between the evolutions required for different observations. Nevertheless, there is an entrenched view that evolution is observed in the characteristics of many objects. Two notable examples are the luminosity distribution of quasars and the angular-size relationship for radio galaxies. It will be shown that the observations for both of these phenomena are fully compatible with a static cosmological model.

11. Quasar Luminosity Distribution

Because of their high redshifts, quasars are excellent objects for probing the distant universe. Since this cosmological model is static, neither the density distribution nor the luminosity distribution of any object should be a function of distance. Consider the density distribution $n(z)$, where z is the usual redshift parameter $z = (\lambda_{\mathrm{observed}}/\lambda_{\mathrm{emitted}} - 1)$. Then

$$z = \exp\left(Hr/c\right) - 1,$$

where r is the distance. Since the range of r is $0 \le r \le \pi R$, the maximum value of z is $84\cdot 0$ and its value at the 'equator' is $8\cdot 2$. Given that the geometry is that for a three-dimensional hyperspherical surface with radius R in a four-dimensional space, the volume out to a distance r is

$$V\left(r\right) = 2\pi R^2 \left(r - \frac{R}{2}\sin\left(\frac{2r}{R}\right)\right) \tag{28}$$

and the density distribution as a function of redshift for an object with a uniform density of n_0 is

$$\begin{aligned} n\left(z\right)dz &= n_0 \frac{dV}{dr}\frac{dr}{dz}dz \\ &= \frac{4\pi R^2 c n_0 \sin^2\left(c\ln\left(1+z\right)/RH\right)}{H\left(1+z\right)}dz\,. \end{aligned} \tag{29}$$

From equations (10) and (21) we find that $HR = \sqrt{2}\,c$ and equation (29) becomes

$$n\,(z)\,dz = \frac{4\pi R^3 n_0 \sin^2\left(\ln\,(1+z)\,/\sqrt{2}\right)}{\sqrt{2}\,(1+z)}dz\,, \tag{30}$$

which has a maximum when $z = 2{\cdot}861$. Now the difficulty of using equation (30) with observations is that most quasar observations have severe selection effects. Boyle *et al.* (1990) measured the spectra of 1400 objects, of which 351 were identified as quasars with redshifts $z < 2{\cdot}2$. The advantage of their observations is that their selection effects were well defined. A full analysis is given in Crawford (1995*b*).

Let a source have a luminosity $L\,(\nu)$ $(\mathrm{W\,hz^{-1}})$ at the emission frequency ν. Then if the energy is conserved, the observed flux density $S\,(\nu)$ $(\mathrm{W\,m^{-2}\,Hz^{-1}})$ at a distance r is the luminosity divided by the area, which is

$$S\,(\nu) = \frac{L\,(\nu)}{4\pi R^2 \sin^2\,(r/R)}\,. \tag{31}$$

However, because of the gravitational interaction there is an energy loss such that the received frequency ν_0 is related to the emitted frequency ν_e by

$$\nu_0 = \nu_e \exp\,(-Hr/c) = \nu_e/\,(1+z)\;. \tag{32}$$

This loss in energy means that the observed flux density is decreased by a factor of $1+z$, but there is an additional bandwidth factor that exactly balances the energy loss factor. In addition, allowance must be made for K-correction (Rowan-Robinson 1984) that relates the observed spectrum to the emitted spectrum. Since it is usual to include the bandwidth factor in the K-correction, the apparent magnitude is

$$\begin{aligned} m = &-\tfrac{5}{2}\log\left(S\,(\nu_0)\right) \\ = &-\tfrac{5}{2}\log\left(L\,(\nu_0)\right) + \tfrac{5}{2}\log\left(4\pi R^2\right) \\ &+ 5\log\left(\sin\left(\frac{c\ln(1+z)}{HR}\right)\right) + \tfrac{5}{2}\log\,(1+z) + K\,(z)\,, \end{aligned}$$

where $K\,(z)$ is the K-correction and, from above, $RH = \sqrt{2}c$. The result of the analysis was that the observations were fitted by a (differential) luminosity function that had a Gaussian shape with a standard deviation of $1{\cdot}52$ magnitudes and a maximum at $M = -22{\cdot}2\,\mathrm{mag}$ (blue). The only caveat was that there appeared to be a deficiency of weak nearby quasars in the sample. Since all cosmological models are locally Euclidean, this must be a selection effect. The fact that the absolute magnitude distribution had a well-defined peak and this was achieved without requiring any evolution is strong support for the static model.

12. Angular Size of Radio Sources

For the geometry of the hypersphere, the observed angular size θ for an object with a redshift of z and projected linear size of D is $\theta = D/R\sin(r/R)$, and in terms of redshift it is

$$\theta = \frac{D}{R\sin\left[c\ln(1+z)/RH\right]}$$

$$= \frac{D}{R\sin\left[\ln(1+z)/\sqrt{2}\right]}.$$

The angular size decreases with z until $z = 8\cdot 2$, where there is a broad minimum, and then it increases again. This model was used (Crawford 1995*a*) to analyse 540 double radio sources (all Faranoff–Riley type II) listed by Nilsson *et al.* (1993). The result was an excellent fit to the radio-source size measurements, much better than the big-bang model with a free choice of its acceleration parameter.

13. Surface Brightness of Galaxies

In an expanding universe, bolometric surface brightness will decrease with redshift as $(1+z)^{-4}$, while in a non-expanding cosmology with tired light it will decrease as $(1+z)^{-1}$. Because it is independent of the geometry of space, it is a powerful test for discriminating between the two cosmologies. The problem is that the measurement of surface brightness is very difficult. Recently Pahre *et al.* (1996) have reported measurements of surface brightness for elliptic galaxies in the clusters Abell 2380 ($z = 0\cdot 23$) and Abell 851 ($z = 0\cdot 41$), and have compared them with the nearby Coma cluster. Their final results are surface brightness measurements for an average elliptic galaxy in the K, B and R_c spectral bands for the Coma and Abell 851 clusters and only the K band for cluster Abell 2380. Although they claim that the results are inconsistent with a tired-light cosmology, their claim is only true for the K band data. The B and R_c band data are consistent with a tired-light cosmology. In addition, the K-corrections for the K band data seem to have been computed using evolving galaxy models, whereas for a valid comparison it should be done for a non-evolving galaxy. Although the difference is small, the K corrections are commensurate with the discrepancy with the tired-light model. It would be more convincing if the K band observations for Abell 851 could be done with a filter redshifted by a factor of $1\cdot 41$.

14. Other Evidence for Evolution

There are, however, more direct observations of evolution that will now be discussed. These are the distribution of absorption lines in quasar spectra, the measurement of the microwave background temperature at high redshift, the time dilation of the type I supernova light curves at large distances, and the Butcher–Oemler effect. For this static cosmology, consider a uniform distribution of objects with number density N and cross-sectional area A. Then their distribution in redshift along a line of sight is (here γ is the exponent and not the Lorentz velocity parameter)

$$\frac{dN}{dz} = \frac{NAc}{H}(1+z)^{\gamma}\ , \tag{33}$$

with $\gamma = -1$. If the absorption lines seen in the spectra of quasars are due to absorption by the Lyman-α line of hydrogen in intervening clouds of gas, and with a uniform distribution of clouds, their predicted redshift distribution should have $\gamma = -1$. However, observations (Hunstead *et al.* 1988; Morris *et al.* 1991; Williger et al 1994; Storrie-Lombardie *et al.* 1996; Barlow & Tytler 1998) show exponents that range from $0{\cdot}8$ to $4{\cdot}6$. Although there is poor agreement amongst the observations, clearly they are all in disagreement with this model. The recent observations of Barlow and Tytler (1998) are of interest in that for the Lyman-α lines they get $\gamma \simeq 1$ but for C IV $\lambda 1548{\cdot}20$ absorption lines they find that the result from Steidel (1990) of $\gamma = -2{\cdot}35 \pm 0{\cdot}77$ is inconsistent with their low-z data point and that equation (33) has a very poor fit.

Observations of absorption lines have complications due to lack of resolution causing lines to be merged and the fact that only a limited range in z (from Lyman-α to Lyman-β) is available from each quasar. However, the major change required in the interpretation of the results for the static cosmology is in the explanation for the broad absorption lines. Traditionally these have been ascribed to Doppler broadening from bulk motions in the clouds, but it is also possible that they are due to energy loss by the gravitational interaction. For example, using equation (22) the 'velocity' width of a cloud of diameter 10^4 pc and density $10\, m_H \mathrm{m}^{-3}$ is $16\ \mathrm{km\,s^{-1}}$, which is typical of the observed linewidths. For a typical column density of $N_{\mathrm{HI}} = 10^{15}\ \mathrm{cm}^{-2}$ this cloud would have a ratio of H I to ionised hydrogen of 3×10^{-5}. A further consequence is that because of the clouds, the observed redshift is not a valid measure of the true distance. For example, suppose the quasar is located in a galactic cluster where we would expect a high local concentration of clouds. Then its redshift would be increased over that expected for the cluster by the extra energy loss in the clouds. The conclusion is that until the nature of the absorption lines better understood and analysed in the context of this theory the evidence for evolution is not convincing.

Another observation that could refute this theory would be that the cosmic microwave background radiation has a higher temperature at large distances. Ge *et al.* (1997) measured the absorption from the ground and excited states of C I (with a redshift of $1{\cdot}9731$) in the quasar QSO 0013–004. They measured the strengths of the $J = 0$ and $J = 1$ fine-structure levels and derived an excitation temperature of $11{\cdot}6 \pm 1{\cdot}0$ K, which after corrections gives a temperature for the surrounding radiation of $7{\cdot}9 \pm 1{\cdot}0$ K that is in good agreement with the redshifted temperature of $8{\cdot}1$ K. At face value this is clear evidence for evolution, but not only are the measurements difficult, they are based on a model for linewidths that does not include broadening due to the gravitational interaction. Until this is done and the results are confirmed for other quasars and by other observers, a static cosmology is not refuted.

Programs that search for supernovae in high-redshift galaxies with large telescopes are now finding many examples and, more importantly, some are being detected before they reach their maximum intensity. Leibundgut *et al.* (1996), Goldhaber *et al.* (1996), and Riess *et al.* (1997) have reported on type 1a supernovae in which they believe that they can identify the type of supernova from its spectral response; by comparing the supernova light curves with reference templates they measured a time dilation that corresponds to that expected for their redshift in a big-bang cosmology. In addition, there is a significant correlation between the rate of decay of the light curve and the intrinsic luminosity (Riess *et al.* 1996) in that brighter supernovae have a slower decline. Hence there may be a bias due to selection effects and the cosmological model used to get the absolute luminosity that is needed to correct for the correlation. However, because of this correlation, uncertainties in matching the exact type of supernova and the occurrence of individual inhomogeneities, many more observations are needed before these results are well established.

The Butcher–Oemler (1978) effect is the observation that at redshifts $z \geq 0{\cdot}3$ the galaxies in rich clusters tend to be bluer than is typical of nearby clusters. Couch *et al.* (1998) have found significant differences in their study of three rich clusters at a redshift of $z = 0{\cdot}31$. However, Andreon and Ettori (1999) looked at a larger sample of X-ray selected clusters and found no evidence for the Butcher–Oemler effect. Their argument is that the effects that are observed are due to selection criteria rather than differences in look-back time. As well as the lack of unambiguous observations, the effect (when present) is only seen at redshifts up to $z \sim 1$, which is only relevant to the local inhomogeneity.

The conclusion is that the Lyman-α forest observations and the cosmic background radiation temperature observations need to be re-evaluated within the static cosmological model in order to see if they show evolution and refute the model. The supernovae results are essentially unchanged in the static model and if they hold up, they make a strong case for evolution that would refute any static model. The Butcher–Oemler effect observations are still not strong enough to make a good argument against a static homogeneous universe.

15. Nuclear Abundance

In this cosmology the universe is dominated by a very high-temperature plasma. Galaxies condense from this plasma, evolve and die. Eventually all of their matter is returned to the plasma. Although nuclear synthesis in stars and supernovae can produce the heavy elements, it cannot produce the very light elements. In big-bang cosmology these are produced early in the expansion when there were high temperatures and a large number of free neutrons. This mechanism is not available in a static cosmology. Nevertheless the temperature of the plasma (2×10^9 K) is high enough to sustain nuclear reactions. The end result is an abundance distribution dominated by hydrogen and with smaller quantities of helium and other light elements. The problem is that the density is so low that the reaction rates may be too small achieve equilibrium within the recycling time. Naturally much further work is needed to quantify this hypothesis.

16. Entropy

Nearly every textbook on elementary physics quotes a proof based on the second law of thermodynamics to show that the entropy of the universe is increasing, but this is in direct conflict with the perfect cosmological principle where total entropy is constant. The conflict can be resolved if it is noted that the formal proof of the second law of thermodynamics requires consideration of an isolated system and the changes that occur with reversible and irreversible heat flows between it and its surroundings. Now there is no doubt that irreversible heat flows occur and lead to an overall increase in entropy. However, the formal proof is flawed in that with gravitational fields one cannot have an isolated system. There is no way to shield gravity. Furthermore, in their delightful book Fang and Li (1989) argued that a self-gravitating system has negative thermal capacity and that such systems cannot be in thermal equilibrium. The crux of their argument is that if energy is added to a self-gravitating system, such as the solar system, then the velocities, and hence the 'temperature', of the bodies decrease. What happens is that from the virial theorem the potential energy (with a zero value for a fully dispersed system) is equal to minus twice the kinetic energy and the total energy is the sum of the potential and kinetic energies which is therefore equal to minus the kinetic energy. Thus we must be very careful in applying simple thermodynamic laws to gravitational systems.

Now consider the gravitational interaction where photons lose energy to the background plasma. Since this process does not depend on temperature it is not a flow of heat energy, rather it is work. Nevertheless we can compute the entropy loss from the radiation field, considered as a heat reservoir, as $-W/T_r$, where W is the energy lost, and similarly the entropy gained by the plasma as W/T_e. Then since $T_e \gg T_r$ there is a net entropy loss. Thus this gravitational interaction not only produces the Hubble redshift but it also acts to decrease the entropy of the universe, thereby balancing the entropy gained in irreversible processes such as the complementary interaction where electrons lose energy to the radiation field.

17. Olber's Paradox

An essential requirement of any cosmology is to be able to explain Olber's paradox (or more correctly de Chesaux's paradox; Harrison 1981) as to why the sky is dark at night. For the big-bang cosmology, although the paradox is partly explained by the universal redshift, the major reason is that the universe has a finite lifetime. For this static cosmology the explanation is entirely due to the redshift. The further we look to distant objects the more the light is redshifted until it is shifted outside our spectral window. Thus in effect we only see light from a finite region. Note that the energy lost by the photons is returned to the intergalactic plasma as part of a cyclic process.

18. Conclusion

The introduction of curvature pressure has wide-ranging astrophysical applications. It is possible that it may resolve the solar neutrino problem but this must await a full analysis using the standard solar model. Although the theory does not prevent the formation of a black hole from cold matter, it does have an important effect on the high-temperature accretion rings, and curvature pressure may provide the engine that produces astrophysical jets.

The greatest strength of this model is that it shows how a stable and static cosmology may exist within the framework of general relativity without a cosmological constant. The model with a homogeneous plasma depends only on one parameter, the average density, which from X-ray observations is taken to be $2{\cdot}05 m_H\,\mathrm{m}^{-3}$. It then predicts that the plasma has a temperature of $2 \times 10^9\,\mathrm{K}$ and that the universe has a radius given by equation (10). It has been shown that for a simple inhomogeneous density distribution, the predicted temperature could easily be much lower and it could be in agreement with the temperature observed for the X-ray background radiation. Inclusion of the gravitational interactions permits the prediction of a Hubble constant of $H = 60{\cdot}2\,\mathrm{km\,s^{-1}\ Mpc^{-1}}$ and a microwave background radiation with a temperature of $3{\cdot}0\,\mathrm{K}$. Dark matter does not exist but arises from the assumption that non-cosmological redshifts are genuine velocities and then using the virial theorem. In this static model most of the non-cosmological velocities are due to gravitational interactions in intervening clouds.

Analysis of the observations for quasar luminosities and the angular size of radio sources shows that they can be fully explained in a static cosmology without requiring any evolution. The implication is that many other observations that require evolution in the big-bang cosmology need to be re-examined within the static cosmology before evolution can be confirmed. The strong evolution shown in the distribution of absorption lines (the Lyman-α forest) is a problem for the static model. However, because of the gravitational interaction that can cause line broadening and the possibility that some of the redshift may come from the clouds that produce the absorption lines, the results cannot at this stage be taken as a refutation of the static model. Although the observations of a redshifted background microwave temperature and the evidence of time dilation in the decay curves of type 1a supernovae appear to show direct evolution, it is too early to be certain. These observations need better statistics and should be analysed within this static model before their apparent evolution is convincing. The theory includes a qualitative model for the generation of the light elements in the high-temperature intergalactic plasma. It is also argued that the effects of gravitational interaction of the microwave background radiation that transfers energy to the high-temperature plasma decrease entropy so that overall the total entropy of the universe is constant. Finally, the sky is dark at night because the light from distant stars is redshifted out of our spectral window.

An important characteristic of this static cosmology is that it is easily refuted: any unequivocal evidence for evolution would disprove the model. Apart from evolution the most discriminating test that would choose between it and the big-bang cosmology would be to compare the differential velocities of galaxies in a cluster with their distance. Whereas the big-bang model requires that there is no correlation, this static cosmology requires that the more distant galaxies will have larger redshifts.

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