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Research article

A New Model for the Expanding Universe

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ABSTRACT

A new cosmological model for the expanding universe is proposed. The model is based on the postulates that (i) radiation (the excited empty space) imparts a repulsive force that expands space and (ii) the attractive gravitational force in the universe is balanced by the repulsive force of radiation instead of by the outward impulse of a primordial big bang event as supposed in the big bang theory.

It seems quite likely that in today's universe the postulated repulsive energy of the photons keeps exact balance with the attractive gravitational energy of the baryons and this balance remains preserved for any given radius of the future expansion. The photon/baryon governed cosmological model (abbreviated as the PB model in the following discussion) requires modification of the energy–momentum tensor in Einstein's field equation, which is, however, completely natural in context of general relativity.

The PB model provides a natural explanation of the flatness or fine-tuning problem without the need for dark matter and dark energy, and it explains the redshift of the cosmic background radiation in accordance with the law of energy conservation. Some further implications of the PB model for the large scale structure formation and motion of galaxies are also discussed.

Subject headings: cosmology, general relativity, repulsive photon energy, cosmic microwave background, flat universe

1. INTRODUCTION

According to the standard big bang model (Peebles et al. 1991), the universe began 10–20 billion years ago as a primeval fireball of extreme density and temperature from an instantaneously expanding point, and it has been expanding and cooling ever since. The tearing force of the expansion is supposed to be the outward impulse of the primordial big bang and it is assumed that with time gravity will slow down the outward velocity.

The theoretical foundation of the big bang cosmological model is based on Einstein‘s fundamental theory of general relativity (Einstein 1915). When general relativity (GR) is applied to the universe as a whole (Einstein 1917), it turns out that space should be either contracting or expanding. The time dependence of the expansion is given by the Friedmann-Lemaitre equation (Friedmann 1922, 1924; Lemaitre 1931):

$$\left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi G}{3}\rho + \frac{c^2}{3}\Lambda - k\frac{c^2}{R^2} \qquad (1)$$

where ρ is the mass density including the contribution from various distant components: from the baryonic mass, from the energy of radiation/c^2, and from every other form of energy/c^2 present in the universe; Λ denotes Einstein’s cosmological constant; and, k represents the space curvature and takes the values +1, −1, or 0 for a closed, open, or flat universe, respectively. High resolution maps of the cosmic microwave background radiation imply a flat universe (Bernardis et al. 2000).

Currently, the hot big bang theory is the broadest accepted theory for the origin and evolution of the universe. It is, however, not complete in its present form and it faces serious problems which could turn out to be impossible to explain within the frame of the big bang cosmological model.

1. 1. The Missing Mass Problem

1. 1. 1. The missing mass problem arose when Zwicky (1933) noticed that the gravitational attraction of the baryonic matter is not sufficient to hold the galactic systems together. The shortfall of the Newtonian gravity occurs at widely different length scales and has been found to be very variable in different galactic systems.

1. 1. 2. As pointed out by Dicke and Peebles (1979), and comprehensively stressed by Guth (1981), a universe can only survive 10 billion years by extremely fine-tuning of the initial values of ρ and the Hubble constant H (Hubble 1929) so that ρ must be very near by the critical value $\rho_{cr} = 3H^2/8\pi G$. The value of $\Omega = \rho/\rho_{cr}$ must be fine-tuned with an accuracy of one part to 10^{18}. In the standard model this incredibly precise initial condition must be assumed without explanation.

Guth (1981) proposed that according to the inflationary theory the early universe had a brief period of extremely rapid expansion during which its diameter increased by a factor of perhaps 10^{50}. The equations that describe the period of inflation have a very attractive feature: from almost any initial condition the universe evolves to precisely the state that had to be assumed as the initial one in the standard model with Ω very near to 1.

However, despite the fact that the universe has existed for about 15 billion years, and therefore according to the standard as well as to the inflationary theory its density should be very near by the critical value, both the standard and the inflationary model contradict the experimental measurements of the observable baryonic mass, which has been found to amount only to a few percent of the critical value (Narlikar 1993; Turner 2001).

1. 1. 3. The Dark Matter and Dark Energy Hypothesis

In order to make the big bang model consistent with observations, many astronomers believe that large quantities of some unidentified dark matter pervade the universe. Astronomers also suspect the existence of dark energy that would produce the accelerated cosmic expansion (Riess et al. 1998). If the dark matter and dark energy is assumed, the big bang model can match each of the critical observations arising from the missing baryonic mass. The trouble with these calculations is that a universe that contains everything is much too complex and enlarges the variety of adjustable parameters.

Meanwhile, the dark matter theory has run into difficulty when it has been applied to galaxies (Aguirre 2002; Milgrom 2002). Modification of the Newtonian dynamic as a possible alternative to the dark matter and dark energy hypothesis has been proposed (Milgrom 1983a, 1983b, 1983c). Milgrom’s law eliminates the need for dark matter in galactic systems; it is, however, entirely empirical, and without an underlying physical foundation.

1. 2. The Red Shift and Energy Conservation Problem

The difficulty with the law of energy conservation in an expanding universe was first noticed by Hubble (1936). He wrote that “redshift by increasing wavelengths must reduce the energy in the quanta. Any plausible interpretation of redshifts must account for this loss of energy.” The conservation of the energy of light photons in transit has been a problem for cosmologists ever since, and some of them have taken the view that in this one case the energy in the universe as a whole is not conserved (Harrison 1981, 275).

1. 3. Alternatives to General Relativity

Furthermore, a variety of alternatives to general relativity have been proposed. Alternative theories that have attracted particular attention are those such as Dirac's theory (1938), the Brans-Dicke theory (1961), and the Hoyle-Narlikar theories (Hoyle 1948; Narliker 1974). Recent modifications of Einstein's gravitational theory suggest alterations to the Friedmann equation at large cosmological scales (Deffayett et al. 2002; Freese & Lewis 2002; Caroll et al. 2003; Arkani-Hamed et al. 2003; Moffat 2004). During the last decades nearly everything, including the constant nature of the natural constants, has been called into question (Musser 1998). Beside dark matter and dark energy, negative matter (Bondi 1991), quintessence (Ostriker & Steinhard 2001), and the existence of multiverses (Tegmark 2003) have been discussed, but not much progress has been made in identifying the elusive dark constituents. If the search for dark matter and dark energy turns out to be unsuccessful, the possibility that the applicability of general relativity to the universe will break down on the cosmic scale cannot be ruled out.

2. PROBLEMS WITH GENERAL RELATIVITY WHEN APPLIED TO THE WHOLE UNIVERSE

The general theory of relativity, which interprets gravity as the curvature of space time, has passed all tests for local phenomenon. However, when applied to the whole universe GR represents only a theoretical framework and it allows the construction of numerous basically different cosmological models such as Einstein's static universe, the Einstein-de Sitter model (1932), the cosmological model of Eddington–Lemaitre (Eddington1930; Lemaitre 1927), and the dynamic, expanding, or contracting universes of Friedmann-Lemaitre (Friedmann 1922, 1924; Lemaitre 1931). It is worth noting that all these cosmological models are mathematically correct and none of them is preferred by GR.

The field equation originally developed by Einstein has the general form

$$R_{ik} - \frac{1}{2} R\, g_{ik} = \frac{8\pi G}{c^4} T_{ik} \tag{2}$$

where R_{ik} is the Ricci tensor, Rg_{ik} the Ricci scalar and T_{ik} represents the matter tensor.

The left-hand side of equation (2) represents the geometrical interpretation of the gravitational field. The theory of gravity is universally considered to be complete as far as the geometrical part is concerned. However, the right hand side is a formal condensation of all those things whose comprehension in the sense of field theory is still problematic (Canuto & Hsieh 1980). In GR any form of energy/c^2, including the energy of radiation, affects the gravitational field and is supposed to cause the expansion to slow down due to the attractive force of gravity. It is believed that the contribution of radiation is small enough to be neglected when calculating the behaviour of the universe today. This interpretation, however, does not follow *eo ipso* from the theory of GR or from some other kind of fundamental physical law. Einstein (1979) wrote: “Not for a moment, of course, did I doubt that this formalism was merely a makeshift to give the general principle of relativity a preliminary closed form,” and he introduced the cosmological constant in order to fit the universe to the desired static model. Because GR never defined the exact nature of matter in context of GR also other interpretations of the matter tensor could turn out to be more successful when applying GR to the universe as a whole. Observations and experiments must determine what matter means and the appropriate interpretation that generates the real world (Harrison 1981, 324).

The purpose of the present paper is to show that the universe could work in a basically different way from that generally assumed today. In the following, I will show that cosmic evolution is describable by the energetic interaction of the baryons and the photons. The proposed photon/baryon governed cosmological model containing only ordinary matter and radiation is simple; it does not require exotic physics and matter, and it obeys the spirit of general relativity. The PB model is based on a new interpretation of the energy–momentum tensor in Einstein‘s field equation, and I will show that this new interpretation violates neither the basic ideas of GR nor the validity of fundamental physical laws.

3. NEW INTERPRETATION OF THE MATTER TENSOR

The basic postulates are that (i) radiation (the excited empty space) imparts a repulsive force that expands space and (ii) the attractive gravitational force in the universe is balanced by the repulsive force of radiation, instead of by the kinetic energy of the expansion as supposed in the big bang theory. Consequently, the matter term in equation (1) has to be decomposed into the sum of contributions from these two different sources of energy: into the matter term, representing the gravitational energy of the baryonic matter; and the energy term for photons which represents the radiation energy, i.e. the energy of the excited empty space. Thus, when applied to the universe as a whole, equation (1) obtains the following form ($\Lambda = 0$; $k = 0$):

$$\left(\frac{\dot{R}}{R}\right)^2 = -\frac{8\pi G}{3N_L}\rho_B + \frac{8\pi\Psi}{3}\rho_{Ph} \qquad (3)$$

The term $(8\pi G/3N_L)\times\rho_B$ is equivalent to Einstein's matter tensor in every respect, containing matter and all forms of energy/c^2 which are associated with a certain physical state of matter. The term $(8\pi\psi/3)\times\rho_{Ph}$ is the new photon term, a true energy term, containing those forms of energy which are considered to be a property of space-time itself, the energy of photons and neutrinos; ψ is a constant, its physical meaning is explained in Section 4. In equation (3) the mass density ρ_M is expressed as baryon density $\rho_B = \rho_M\times N_L$. The convenience of this change in notation is explained below.

Some conspicuous peculiarities of the physical properties of matter and radiation support the above described interpretation of the matter tensor. On the one hand, considering the different forms of energy involved in gravitation, kinetic energy, thermal energy, and so on, it is obvious that all these energies represent a certain physical state of matter, or in other words, they are (changeable or temporary) properties of matter, which is the carrier for these types of energy. On the other hand, light is not a physical property of matter, it is rather a physical property of space-time itself, a kind of excitation of the empty space (Genz 1999, 312; Krasnoholovets 2002).

The basic differences between the gravitational interactions of matter and radiation are obvious: matter tends to condense whilst radiation always spreads out. Light does not interact with light by gravitation (Fritzsch 1997, 108; Faraoni & Dumse 1998); it is hard to imagine a gravitational condensation of pure radiation (Gamow 1948). There are no compelling physical reasons to assume that the energy of radiation has to be condensed in a general sum together with matter or with other forms of energy carried by matter.

Furthermore, as far as the origin of redshift is concerned, the only indubitable observational fact is that the wavelength of radiation increases to the same extent as the radius of the universe expands. That redshift is caused by the expansion of space-time due to the outward impulse of a primordial big bang event is merely a result of interpretation. However, the opposite view that light itself expands space cannot be ruled out by known experimental evidence. There is no scientific proof that one or the other of these approaches is the correct approach to use in cosmology.

At the present time the basic postulate of the PB model has to be accepted without further evidence. However, as I will show in Section 9, the new energy term could possibly produce observable effects in the motion of galaxies.

4. THE PHOTON/BARYON GOVERNED UNIVERSE

The PB model differs from that of the big bang model in its basic assumption that the attractive gravitational energy in the universe is balanced by the repulsive energy of radiation, instead of by the kinetic energy of expansion as supposed in the big bang theory. Thus, when applied to the universe as a whole, by simple rearrangement of equation (3) we have:

$$\left(\frac{\dot{R}}{R}\right)^2 = -\frac{2}{R^2}\frac{G N_B}{N_L R} + \frac{2}{R^2}\frac{\Psi N_\lambda}{R} \tag{4}$$

where N_B is the total number of baryons and N_λ is the total number of photons in the universe. N_L is the Loschmidt number and ψ is a constant converting the total energy (E^λ_{tot}) of the microwave background radiation as observed today into the energy per unit mass (E^λ_{tot}/M_U) corresponding to any given radius R_U of the universe. The numerical value of ψ can be calculated to 1.4×10^{-41} cm^3 s^{-2}. In equation (4) the term GN_B/N_LR_U represents the gravitational energy and the term $\psi N_\lambda/R_U$ represents the energy of radiation per unit mass. N_B and N_λ are conserved quantities (neither of these is strictly conserved but the rates of decay are rather insignificant) and therefore on the cosmic scale both types of energy are inversely proportional to R_U. It should be emphasized that the applicability of equations (3 and 4) is strictly confined to the universe as a whole. The wavelength of the cosmic background radiation in transit through space is nearly independent of local mass concentrations; it depends only on the radius R_U.

5. THE FLAT PHOTON/BARYON GOVERNED UNIVERSE

In order to construct a solution which corresponds to a flat universe the mass M_U and the radius R_U have to be adjusted to the proper value. For parameterization the following data were used: $R_U = 1.4175 \times 10^{28}$ cm, corresponding to an age of the universe of 15 billion years; $T_\lambda = 2.726$ K, temperature of the cosmic background radiation; $N_\lambda = 4.898 \times 10^{87}$, corresponding to the total number of photons (other sources of radiation were not taken into account). From this the total mass can be calculated as $M_U = 1.028 \times 10^{54}$g, in accordance with the best literature data (Narlikar 1993; Turner 2001). With the above parameter both the gravitational energy and the energy of the cosmic background radiation amount to 4.84×10^{18} ergs g^{-1}, and according to equation (4) the exact balance between these two opposite forms of energy remains preserved for any given radius R_U of the future expansion.

6. THE EXPANSION OF THE PHOTON/BARYON GOVERNED UNIVERSE

I have shown in Section 5 that in today's universe the positive energy of radiation keeps an exact balance with the negative gravitational energy of the baryons. The total energy as measured by the space curvature, $GM_U/R_U + \psi N_\lambda/R_U$, is therefore zero. Looking back in time, however, at the radius $R_U = 2GM_U/c^2$ the term for the gravitational potential in eq. (4) increases to c^2 which is the maximum value for the gravitational potential allowed by GR.

The energy of radiation, however, is not limited by the mass-energy equivalence principle and it can increase continuously with decreasing radius R_U. At radii $< 2GM_U/c^2$ the repulsive energy of radiation exceeds the gravitational attraction and such a system would start to expand in a natural way. At the time of recombination (T = 3000 K) for example, the energy of the background radiation was about 5.33×10^{21} ergs g^{-1} whilst the gravitational energy still remains c^2 ergs g^{-1}. With these data the velocity of the expansion can be calculated from equation (6) as $v = 9.88 \times 10^{10}$ cm s^{-1}. It seems quite possible that in this era of evolution the cosmic expansion was driven by the large excess of repulsive radiation energy.

It is also possible for the PB model to provide a plausible mechanism for the expansion starting off in an apparently steady state origin at radii $R_U \geq GM/c^2$

$$\left(\frac{\dot{R}}{R}\right)^2 = -\frac{2}{R^2}\frac{G N_b}{N_L R} + \frac{2}{R^2}\frac{\Psi N_\lambda}{R} = 0 \tag{5}$$

Due to the large number of photons compared with that of the baryons, the background radiation is absolutely smooth, whilst the gravitational energy field is heterogeneous. Matter is not homogeneously and isotropically distributed over space as cosmic matter appears in strongly pronounced hierarchical structures from the smallest to the largest length scales forming atomic nuclei, stars, galaxies, and galaxy clusters. In today's universe the 3-dimensional distribution of luminous matter has a "soap-bubble" appearance with the visible galaxies on the surface of the soap bubbles (Landy 1999). The gravitational potential of a solid sphere filled homogeneously and isotropically with matter is 1.2GM/R. The gravitational potential inside a hollowed-out sphere containing only photons, with a thin shell of matter situated on the surface of the sphere, amounts to GM/R. The repulsive energy of radiation$\times$g^{-1}, however, remains unchanged at 1.2GM/R, due to the homogeneous and isotropic distribution of the photons over space. Consequently, if matter is not homogeneously distributed over space, the expansive energy of radiation inside the voids exceeds the attractive gravitational energy and the empty space accordingly expands. The excess of radiation energy inside empty spaces causes a true instability which could drive the cosmic expansion, which is due only to the postulated repulsive energy of radiation. Unfortunately, there are considerable difficulties in inferring the excess of radiation energy inside the voids quantitatively. The energy difference depends on the radius of the void and on the thickness of the shell, and on the distribution of mass within the shell. A detailed mathematical treatment of this problem is missing in literature.

7. THE INFLUENCE OF THE PHOTON TERM ON LOCAL DYNAMICS

Because of the photon term in equation (4), it is necessary to pose the question as to whether the new term affects the dynamics of local systems. Since we assume that the universe is homogeneous and isotropic on the cosmic scale and contains positive and negative energy in the same amounts, the positive and the negative energies cancel out due to the uniform density and symmetry. The formation of galaxies will cause a local increase in gravitational potential above the overall net zero level according to the Einstein equation. The repulsive energy of radiation inside the galaxies can be neglected for reasons of magnitude because it is still almost exactly balanced on the cosmic scale. All the appearances of local gravity obey the Einstein equation. Expansion due to the repulsive energy of radiation occurs strictly on the cosmic scale.

8. REDSHIFT AND ENERGY CONSERVATION

According to the PB model, the energy required for the expansion of the mass M_U of the universe, versus its own gravitational attraction, is supplied by the radiation energy. The energy of the cosmic background radiation decreases according to the amount of work done in the expansion of the volume of the universe.

$$\Delta E = -\int_{r_1}^{r_2} \frac{GMm}{r^2} dr = -\left(\frac{GMm}{r_1} - \frac{GMm}{r_2} \right) \qquad (6)$$

The expansion is accompanied by an equivalent redshift and the law of energy conservation is not violated.

9. COSMOLOGICAL IMPLICATIONS

9. 1. Galaxy and Large Scale Structure Formation

The problem is that galaxy formation in a purely baryonic universe does not work. The gravitational influence alone would have made it almost impossible for baryonic matter to form galaxies and large scale structures in a time as short as 10−20 billion years.

The PB model could possibly provide a plausible mechanism for generating large scale structures from the pre-galactic, homogeneous, and isotropic mass distribution without the need for dark matter. If we start with a uniformly diffused nebula consisting of hydrogen atoms and photons, the hydrogen atoms fill only a small part of about 10^{-20} (v/v) of the total volume of the universe. The process that generates large scale cosmic structures from such a quasi-empty universe is simple. Equation (4) shows that for $R_U < 2GM_U/c^2$ the repulsive energy of radiation exceeds the gravitational attraction; the empty space accordingly expands, progressively compressing particles outside the empty spaces into the first protogalaxies. It seems quite possible that this evolutionary process could have started off immediately after recombination driven by the vast excess of repulsive radiation energy.

9. 2. Modification of Newtonian Gravity on the Galactic Scale

The PB model possibly could be applied successfully to further problems of contemporary big bang cosmology. Jackson (1970) and Formann (1970) have shown that negative Λ forces could produce observable effects in the motion of galaxies due to the modification of space curvature in the outer shell of the clusters. In the context of the PB model, the internal dynamic of a self-gravitating system is affected by the external acceleration field and this predicts the need for a regular modification of the Newtonian gravity on the galactic scale. Galaxies and clusters of galaxies are embedded in large empty spaces, and I have shown in Section 6 that inside the empty spaces the repulsive energy of radiation exceeds the gravitational attraction. All objects that exist within the empty space are embedded in this high radiation pressure environment. In GR space-time is supposed to be elastic and can bend, stretch, expand, and contract. It is to be expected that the radiation term in equation (4) will cause a modification of the space-time curvature, especially in the outer shell of galaxy clusters, possibly acting like an inverse-square attraction.

It is, however, not within the scope of this work to give a detailed mathematical solution to the problems described in Sections 9. 1. and 9. 2.

9. 3. The Evolution of the PB Universe

I will consider a new scenario which is capable of describing the evolution of the universe in a theory which is all of a piece. According to current speculation about the origin of matter, the infant universe was an extremely hot, dense cauldron of radiation and it began with a zero baryon number; baryons were formed later by grand unification reactions (Zee 1980). If we accept that radiation imparts the postulated repulsive force, a vast supply of repulsive radiation energy was therefore associated with the big bang event, which provided a large excess of energy to expand space with a velocity much higher than the current speed of light. If the speed of expansion was faster at the beginning of the universe, it would be able to pass through a space larger than our present horizon, thereby accounting for the uniformity in energy and density distribution. This scenario is consistent with the inflationary scenario and the variable speed of light (VSL) theory (Moffat 1993; Barrow 1999; Magueijo 2000; Davies, Davis, & Lineweaver 2002). After a brief inflationary instant some of the radiation condensed into elementary particles and single atomic nuclei. Within the meaning of the PB cosmological model, the attractive energy of gravitation came into being in this short era of matter formation and the physical processes leading to the formation of baryons and photons with a fixed ratio, $\theta = N_\lambda/N_B$, were governed by the law of energy conservation, which requires that the total energy in the universe as measured by the space curvature, $GM_U/R_U + \psi N_\lambda/R_U$, must have zero net value. In this scenario the problem of fine-tuning simply does not exist. Equation (4) means that the energy balance in the universe is determined by the ratio θ of the number of baryons to the number of photons. According to the grand unifying theories (GUT) the ratio θ is fixed by microphysics and has nothing to do with initial conditions (Yoshimura 1978; Weinberg 1979; Zee 1980). There is hope that future development of GUT could help to calculate θ *ab initio* and thus equation (4) could be parameterized without further assumptions.

The further evolution of the universe follows the scheme as described in Section 6. One advantage that the hypothesis described above would have over inflation is that it works with forms of matter and radiation that are known to be present in the universe today.

REFERENCES

Aguirre, A. 2002, Scientific American, August, 36

Arkani-Hamed, N., Hsin-Chia Cheng, Luti, M. A., & Mukohyama, S. 2003, hep-th/0312099

Barrow, J. D. 1999, Phys. Rev. D59, 043515

Bernardies de, P., et al. 2000, Nature, 404, 955

Bondi, H. 1991, Bild der Wissenschaft, 5, 88

Brans, C. & Dicke, R. H. 1961, Physical Reviews, 124, 925

Canuto, V., Hsieh, & S.-H. 1980, Physical Review Letters, 44, 695

Carroll, S. M., Duvvari, M. T., & Turner, M. S. 2003, astro-ph/0306438

Davies, P. C. B., Davis, T. M., & Lineweaver, C. H. 2002, Nature, 418, 602

Deffayet, D., Dvali, G., & Gabadadze, G. 2002, Phys. Rev., D 65, 044023

Dicke, R. H. & Peebles, P. J. E. 1979, in General Relativity: An Einstein Centenary Survey, ed. S.W. Hawking, & W. Israel (London: Cambridge University Press)

Dirac, P. A. M. 1938, Proc. Roy. Soc., A165, 199

Eddington, A. S. 1930, MNRAS, 90, 668

Einstein, A. 1915, Sitzungsberichte Berl. Akad

Einstein, A. 1917, Sitzungberichte Berl. Akad

Einstein, A., & deSitter, W. 1932, Proc. Nat. Acad. Sci., 18, 213

Einstein, A. 1979, in Autobiographical Notes, ed. P.A. Schilpp (Chicago: Open Court Publishing Company)

Faraoni, V. & Dumse, R. M. 1998, gr- qc/9811052

Formann, W. R. 1970, ApJ, 159, 719

Freese, K. & Lewis, M. 2002, Phys. Lett., B 540, 1

Friedmann, A. 1922, Zeitschrift für Physik, 10, 377

Friedmann, A. 1924, Zeitschrift für Physik, 21, 326

Fritzsch, H. 1997, Die verbogene Raumzeit(München: Piper-Verlag).

Gamow, G. 1948, Nature, 162, 680

Genz, H. 1999, Nothingness: The Science of Empty Space (Cambridge, Mass: Perseus Books)

Guth, A. H. 1981, Physical Review D, 23, 347.

Harrison, E. R., 1981, Cosmology: The Science of the Universe (Cambridge University Press)

Hoyle, F. 1948, MNRAS, 108, 372

Hubble, E. 1929, Proc. Nat. Acad. Sci., 15, 168

Hubble, E. 1936, The Realm of the Nebulae (Yale University Press)

Jackson, J. C. 1970, MNRAS, 148, 249

Krasnoholovets, V. 2002, Annales de la Foundation Louis de Broglie, 27, 93

Landy, S. D. 1999, Scientific American, June, 38

Lemaitre, G. 1927, Annales de Société Scientifique de Bruxelles, 47A, 49

Lemaitre, G. 1931, MNRAS, 91, 483

Magueijo, J. 2000, Phys. Rev. D62, 103521

Milgrom, M. 1983 a, ApJ, 270, 365

Milgrom, M. 1983 b, ApJ, 270, 371

Milgrom, M. 1983 c, ApJ, 270, 384

Milgrom, M. 2002, Scientific American, August, 33

Moffat, J. W. 1993, International Journal of Modern Physics D, 2, 351

Moffat, J. W. 2004, astro-ph/0403266

Musser, G. 1998, Scientific American, November, 13

Narlikar, J. V. 1974, in Cosmology Now, ed. J. Laurie (British Broadcasting Corp.)

Narlikar, J. V. 1993, Introduction to Cosmology (London: Cambridge University Press)

Ostriker, J. P. & Steinhard, P. J. 2001, Scientific American, January, 37

Peebles, P. J. E., Schramm, D. N., Turner, E. L., & Kron, R. G. 1991, Nature, 352, 769

Riess, A. G., et al. 1998, AJ, 116, 1009

Tegmark, M. 2003, Scientific American, May, 41

Tolman, R. C. 1987, Relativity, Thermodynamics, and Cosmology (New York: Dover Publ. Inc.)

Turner, M. S. 2001, astro-ph/0106035

Weinberg, S. 1979, Physical Review Letters, 42, 850

Yoshimura, M. 1978, Physical Review Letters, 41, 281

Zee, A. 1980, Physical Review Letters, 44, 703

Zwicky, F. 1933, Helv. Phys. Acta, 6, 110