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F. W. STECKER

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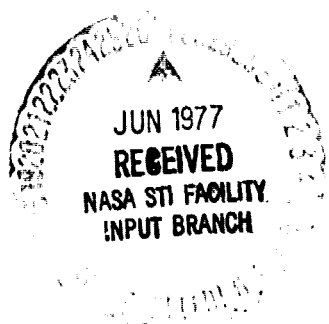

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γ-RAYS AND THE CASE FOR BARYON SYMMETRIC BIG-BANG COSMOLOGY

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The terrible tragedies of science are the horrible murders of beautiful theories by ugly facts.[1]

Reports of my death are greatly exaggerated.

- Mark Twain

ABSTRACT

The baryon symmetric big-bang cosmologies offer an explanation of the present photon-baryon ratio in the universe, the best present explanation of the diffuse γ-ray background spectrum in the 1-200 MeV range, and a mechanism for galaxy formation. In the context of an open universe model, the value of Ω which best fits the present γ-ray data is $\Omega \approx 0.1$ which does not conflict with upper limits on Comptonization distortion of the 3K background radiation. In regard to He production, evidence is discussed that nucleosynthesis of He may have taken place after the galaxies were formed.

Keywords: Cosmology, Gamma-Ray Background, Antimatter

1. INTRODUCTION

Two distinct big-bang cosmologies exist at present in the literature. One is the standard big-bang cosmology. In this cosmology, there existed at the beginning of the big-bang a slight excess of baryons over antibaryons with $\frac{N - \bar{N}}{N + \bar{N}} \sim 10^{-10}$. We shall therefore refer to this cosmology as the partially symmetric big-bang (PSBB). At present, there is no proposed explanation for such a broken symmetry on a universal scale, however, some speculation has been made in this regard (Ref. 1).

The other cosmology, the baryon symmetric big-bang (BSBB), postulates equal amounts of matter and antimatter, since baryons and antibaryons are always produced in pairs in a hot radiation field in thermal equilibrium. In order that the whole universe should not have annihilated in a BSBB, remnant particles and antiparticles must ultimately be separated into regions of like material and this separation must ultimately exist over regions the size of galaxy clusters (Refs. 2,3). Such a separation cannot have been the result of thermal fluctuations (Refs. 4-6). Thus, one may either postulate a separation as an initial condition on the big-bang (Refs. 7, 8) or try to show that some physical separation mechanism could arise naturally and explore its consequences (Ref. 9). Omnès' work on the BSBB has been reported in several papers and later reviewed (Ref. 10). His demonstration of a possible separation mechanism has been supported in calculations by Aldrovandi and Caser (Ref. 11) and Cisneros (Ref. 12).

Basically, aside from physical symmetry considerations, there are three advantages which make the BSBB an attractive theory. (1) It provides possible physical explanation for the entropy per baryon in the universe (photo-baryon ratio), (2) it offers at present the only satisfactory explanation of the γ-ray background radiation in the 1-100 MeV range (Refs. 2,13,14) and (3) it provides for a promising theory of galaxy formation from annihilation driven turbulence (Refs. 2,15) free of the serious problems of radiation dissipation encountered in the standard PSBB cosmology (see, e.g., Ref. 16). On the other hand, two serious points have arisen which have put BSBB cosmologies in question. These are (1) the nucleosynthesis question and (2) the question of distortions of the microwave blackbody background radiation. We will thus address ourselves to these points and modify the previous discussion of Stecker, Morgan and Bredekamp (Ref. 13) to provide a more satisfactory analysis in view of present data.[2]

[1] Paraphrase of a remark of T. H. Huxley by W. A. Fowler as oft quoted by G. Steigman.

[2] Various other points have been made by Steigman (Ref. 22) in a review highly critical of BSBB cosmologies. However, some of these points are either erroneous or misleading while others are unimportant. Steigman's review will not be discussed here further. For a rebuttal of some of these points, see Refs. 2 and 23. There remains the question as to the efficiency of the Omnès separation mechanism. We will take the view here that the physics and astrophysics of this question is not well enough known to further resolve the question and we therefore adopt BSBB as the starting point of further discussion.

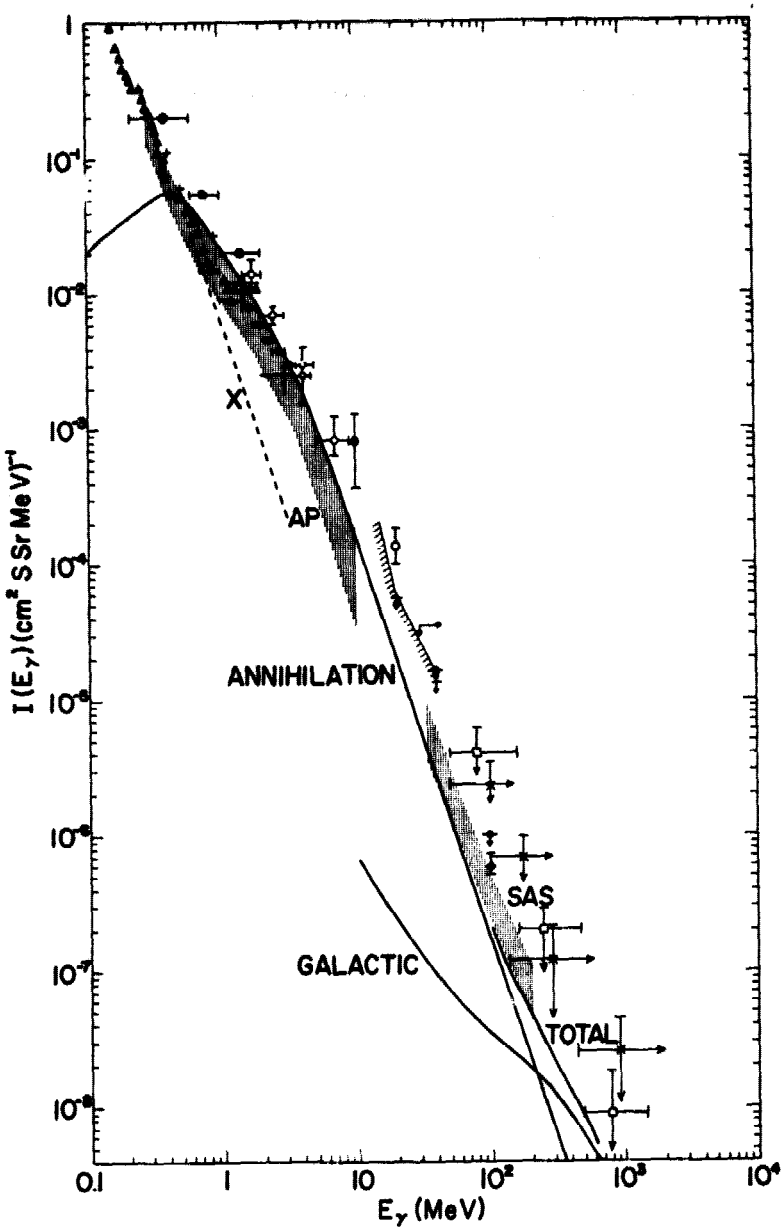

Figure 1. Theoretical spectra (Ref. 21) and observational data on the γ-ray background spectrum as discussed in the text.

2. THE γ-RAY BACKGROUND

Figure 1 shows the observational data on the γ-ray background spectrum as compiled by Stecker, Puget and Bredekamp (Ref. 13) and Stecker (Ref. 14) and updated with the revised Apollo data (AP) of Trombka et al. (Ref. 17). Data of Makino (Ref. 18) are not shown, but are in agreement with other data shown. The dashed line marked X is an extrapolation of data from the X-ray range of Mazets et al (Ref. 12). A theoretical estimate of the galactic contribution to the high latitude flux at high energy as calculated by Stecker (Refs. 20, 21) is also shown. The galactic component has the effect of making the total spectrum (T) appear flatter. This has also been pointed out by Schlickeiser and Thielheim (Ref. 24).[3]

The theoretical curve marked "annihilation" is the annihilation γ-ray spectrum calculated using the method of Stecker, Morgan and Bredekamp (Ref. 13) using a mean universal gas density $n_0 = 3 \times 10^{-7}$ cm^{-3} (Ref. 21). With a Hubble constant H_0=50 km/s/Mpc, this corresponds to a value of Ω=0.1 where Ω is the ratio of the mass of the universe to the mass needed to gravitationally close the universe.

The density n_0 adopted here fits the more recent revised Apollo data (Ref. 17) better than the value $n_0 = 10^{-5}$ cm^{-3} used by Stecker, Morgan and Bredekamp (Ref. 13) corresponding to $\Omega = 1$ with $H_0 = 100$/km/s/Mpc. This is because the newer data show a less pronounced shelf near 1 MeV, such a feature being an absorption effect which becomes more pronounced in a higher density universe (Ref. 25). The position of the shelf is also shifted to somewhat lower energy because the universe in this case, being less dense, becomes opaque at a somewhat higher redshift.

It is interesting to note that the values H_0 = 50 km/s/Mpc, $\Omega = 0.1$ are more in line with present observational evidence regarding these parameters (Ref. 26) and eliminate the problem of annihilation producing so much distortion in the microwave blackbody spectrum as to be in conflict with the observations (see Section 3). In particular Gott and Turner (Ref. 26) estimate that the mass in galaxies gives $\Omega_G = 0.08$ and that although $\Omega \geq \Omega_G$, $\Omega_G \propto \Omega$.

Other attempts have recently been made to account for the background radiation at $E_\gamma \geq 100$ MeV as being due to radiation from the galactic halo or from external galaxies (Refs. 27, 28). It should, however, be noted that spectra from these processes are too flat to account for the shape of the spectrum between 1 and 100 MeV. The Compton spectrum from the halo was first calculated by Felten and Morrison (Ref. 29) and is roughly expected to be $\sim E^{-2}$ or flatter. Spectra from external galaxies should be similar to that of our own, which according to Fichtel et al. (Ref. 30) has a spectrum $\sim E^{-1.6\pm0.2}$.

[3] A recent analysis of the latitude distribution of the γ-ray data above and below 100 MeV, discussed by C. E. Fichtel at the April 1977 meeting of the American Physical Society, supports the model presented in Figure 1 with the galactic component dominating at the higher energies and an E^{-3} extragalactic component dominating at the lower energies.

Another recent suggestion by Rocchia, Ducros, and Goffet (Ref. 31) has recently proposed an explanation of the X- and γ-ray background as due to extragalactic point sources at low redshifts. This explanation requires that, in order to fit the spectrum below 10 MeV, the spectral index Γ must be $\Gamma < 2$ in the 10-100 MeV range, with more γ-rays predicted at 100 MeV than observed. The observations imply $\Gamma \approx 3$ in the 10-100 MeV range. In addition, these authors have not demonstrated sufficient sources to explain the intensity of the γ-ray background or the existence of even one source with the required spectral characteristics.

Page and Hawking (Ref. 32) have pointed out that observations of the γ-ray background place an upper limit on the number of small black holes in the universe. Here again, the predicted spectrum from this process does not match the observed spectrum.

Earlier suggestions of alternate explanations of the γ-ray background observations meet similar difficulties and they have been previously discussed in Ref. 14.

The annihilation hypothesis in the BSBB, yielding a spectrum which goes roughly as E^{-3} at high energies, thus appears at present to be the only theoretical process capable of producing as steep a spectrum as that indicated by the observations with the exception of the primodial cosmic-ray hypothesis (Refs. 33, 34). However, the latter hypothesis appears now to give too flat a spectrum in the region near 1 MeV and it also faces other objections (Ref. 14). We thus conclude that when the γ-ray background spectrum over the entire energy range (1-200 MeV) is considered (rather than simply the integral flux above 100 MeV), one finds observational support for the BSBB cosmology.

3. DISTORTION OF THE BLACKBODY BACKGROUND SPECTRUM

There are two types of distortion of the blackbody background radiation associated with baryon symmetric cosmologies (1) distortion due to bremsstrahlung radiation of electrons of higher temperature than the blackbody radiation which affects the Rayleigh-Jeans part of the spectrum and (2) distortion from Thomson interactions after the decoupling epoch which affects the Wein part of the spectrum (see, e.g., Ref. 35 and references therein). The Rayleigh-Jeans part of the spectrum is affected by annihilation taking place at redshifts $\sim 2 \times 10^5 \leq z \leq \sim 3 \times 10^7 (10^{-4} \lesssim T \lesssim 10^{-2}$ MeV) and it is difficult to determine the precise amount of annihilation to expect at this remote period; it depends on the details of the coalescence process. Indeed, extrapolation of the γ-ray data would indicate that possibly as much as 99.999% of the annihilation may have been accomplished by this epoch whereas the calculations of Illiaronov and Sunyaev (Ref. 36) would put a lower limit of 96.5-99% on this value. For the specific coalescence model of Aldrovandi, et al. (Ref. 37), Ramani and Puget (Ref. 38) have calculated too much distortion in the Rayleigh-Jeans region unless $\Omega \lesssim 0.01$.

The high frequency distortion, sometimes referred to as Comptonization, has been treated in Refs. 38-41. Refs. 39 and 40 conclude that the high frequency distortion predicted by the model of Stecker and Puget (Ref. 2) is not in conflict with

the observations. Refs. 38 and 41 place limits on the value of Ω allowed by requiring no conflict with the observations.

The parameter characterizing Comptonization distortion is defined as

$$y = \tfrac{1}{4} \int_0^{z_{th}} dz \, \frac{d\varepsilon(z)}{\varepsilon_\gamma(z)} \qquad (1)$$

where $d\varepsilon(z)$ is the energy density dissipated at redshift z due to annihilation, $\varepsilon_\gamma(z)$ is the energy density of the radiation at redshift z and z_{th} is the redshift above which complete thermalization can take place ($z_{th} = 3.5 \times 10^4 \, \Omega^{-\frac{1}{2}}$ for $H_0 = 50$/km/s/Mpc). Ramani and Puget (Ref. 38) conclude that the presently proposed coalescence mechanisms are so inefficient as to yield

$$y \gtrsim 0.7 \, \Omega^{7/4} \qquad (2)$$

Field and Perrenod (Ref. 42) have made a χ^2 analysis of the present observational data on the high frequency side of the blackbody curve and conclude that within 90% confidence limits

$$1.3 \times 10^{-2} < y < 5 \times 10^{-2} \qquad (3)$$

It would follow then from (2) and (3), that according to the analysis of Ramani and Puget (Ref. 38), only for open universes with $\Omega \lesssim 0.22$ will there be no conflict with the observations.

Jones and Steigman (Ref. 41) conclude that for the coalescence model of Aldrovandi et al. (Ref. 37)

$$y = \frac{11.8\Omega^{4/3}}{z_{rec}} \quad (H_0 = 50 \text{ km/s/Mpc}) \qquad (4)$$

where the redshift for recombination z_{rec} for the BSBB is ~ 600 (Ref. 2).

It then follows from (2) and (4) that values of $\Omega \lesssim 2$ are allowed by the observations. Thus, only the calculations of Ref. 38 require an open model ($\Omega \lesssim 0.22$). The value of $\Omega = 0.1$ used in Figure 1 to fit the γ-ray observations is therefore not in obvious conflict with any of the Comptonization distortion calculations in the literature.

4. NUCLEOSYNTHESIS

It has been concluded that within the context of the Omnès coalescence model, nucleosynthesis cannot take place in the BSBB (Refs. 43, 44). This is because at the time nucleosynthesis would occur the mean size of the regions of matter and antimatter resulting from the coalescence process considered by Omnès is smaller than the neutron diffusion length for escape from these regions. Thus, the neutrons would be annihilated before they can participate in the nucleosynthesis process. There are, of course, two ways out of this difficulty. (1) Due to some more efficient, as yet unknown, coalescence process, or as a result of initial conditions (Ref. 7, 8), the size of the separate regions of matter and antimatter is larger than the neutron diffusion length. Combes et al. (Ref. 44) find the required condition to be that the region size $\gtrsim 1.5 \times 10^8$ cm at a time corresponding to $T_{BB} = 1$ MeV. (2) Nucleosynthesis did not take place in the big bang, but rather took place in "little bangs" early in the life of galaxies (Ref. 45).

Optical observations of the relative abundance of He in various external galaxies have indicated a significant variation in the abundance which would not be expected if the He was produced uniformly in the big-bang (Ref. 46).

5. ANTINUCLEUS

The presence of antiprotons in the cosmic radiation would not necessarily support the BSBB cosmology since antiprotons can be produced as secondary particles in cosmic-ray interactions (see, e.g. Ref. 47). However, the presence of an antinucleus in the cosmic radiation would give strong support to the BSBB. Therefore, it is of interest to note that a heavy antinucleus may have recently been detected (Ref. 48).

6. DISCUSSION

The baryon symmetric big-bang cosmologies (BSBB) requiring no postulated symmetry in baryon number versus antibaryon number, offer several advantages over the standard, partially symmetric (PSBB) cosmologies. The BSBB models offer an explanation of the present photon-baryon ratio in the universe, the best present explanation of the diffuse γ-ray background spectrum and a mechanism for galaxy formation. In the context of an open universe model, the value of Ω which best fits the γ-ray data is $\Omega \simeq 0.1$. A BSBB cosmology with $\Omega = 0.1$ will not be in conflict with the observational upper limits on Comptonization distortion of the blackbody background radiation. Nucleosynthesis of He in the early stages of the BSBB may not be possible within the context of our present understanding of the coalescence mechanisms, however, evidence is discussed that nucleosynthesis of He may have taken place after galaxies were formed.

In short, the problems associated with BSBB cosmology appear to be no more serious than those associated with standard PSBB cosmology, e.g., galaxy formation is difficult to understand in the context of the standard model. A theory of BSBB cosmology is far from complete but its potential advantages over the standard model offer, in the words of Martin Rees (Ref. 49) "... an attractive enough goal to justify and motivate further development of these ideas."

It is regrettable that modern scientific cosmology has sometimes led to the dogmatism typical of the ancient cosmological schemes. The fact that we have so few observational facts regarding the early universe should remind us of freedom from restrictions which we presently have in considering new and potentially fruitful points of view. It is hoped that others will be encouraged to further explore and develop the baryon symmetric big-bang cosmology.

There are more things in heaven and earth
Horatio than are dreamt of in your philosophy.

- Shakespeare (Hamlet)

7. ACKNOWLEDGMENT

I wish to thank Professor Geoffrey R. Burbidge for bringing to my attention the data on the He/H abundance ratios in other galaxies and the important cosmological consequences of these data.

8. REFERENCES

1. Kuzmin, V. A. (1971) Izv. Akad, Nauk SSSR, Ser. Fiz. 35, 2088.

2. Stecker, F. W. and Puget, J. L. (1972) Ap. J. 178, 57.

3. Bel, N. and Martin, P. (1975) Astron. and Ap. 46, 455.

4. Alpher, R. A., Follin, J. W. and Herman, R. C. (1953) Phys. Rev. 92, 1347.

5. Zel'dovich, Ya. B. (1965) Advan. Astr. and Ap. 3, 242.

6. Chiu, H. Y. (1966) Phys. Rev. Letters 17, 712.

7. Harrison, E. R. (1967) Phys. Rev. Letters 18, 1011.

8. Harrison, E. R. (1968) Phys. Rev. 167, 1170.

9. Omnès, R. (1969) Phys. Rev. Letters 23, 38.

10. Omnès, R. (1972) Phys. Rpts. 3C, 1.

11. Aldrovandi, R. and Caser, S. (1972) Nucl. Phys. B39, 306.

12. Cisneros, A. (1973) Phys. Rev. D7, 362.

13. Stecker, F. W., Morgan, D. L. and Bredekamp, J. H. (1971) Phys. Rev. Letters 27, 1469.

14. Stecker, F. W. (1975) in Origin of Cosmic Rays, ed. J. L. Osborne and A. W. Wolfendale (Dordrecht: Reidel) p. 267.

15. Dallaporta, N., Danese, L. and Lucchin, F. (1974) Ap. and Space Sci. 27, 497.

16. Jones, B. J. T. (1973) Ap. J. 181, 269.

17. Trombka, J. I., Dyer, C. S., Evans, L. G., Bielefeld, M. J., Seltzer, S. M. and Metzger, A. E. (1977) Ap. J. 212, 925.

18. Makino, F. (1975) Ap. and Space Sci. 37, 115.

19. Mazets, E. P., Golenetskii, S. V., Il'inskii, V. N., Gur'yan, Yu. A., and Kharitonova, T. V. (1975) Ap. Space Sci. 33, 347.

20. Stecker, F. W. (1976) in The Structure and Content of the Galaxy and Galactic Gamma Rays NASA CP-002 (Washington: U.S. Gov't Printing Office) p. 315.

21. Stecker, F. W. (1977) Ap. J. 212, 60.

22. Steigman, G. (1976) Ann. Rev. Astr. Ap. 14, 339.

23. Omnès, R. (1973) Ann. New York Acad. Sci. 224, 339.

24. Schlickeiser, R., and Thietheim, K. O. (1976) Nature, 261, 478.

25. Stecker, F. W. (1973) Nature Phys. Sci. 241, 74.

26. Gott, J. R. III and Turner, E. L. (1976) Ap. J. 209, 1.

27. Strong, A. W., Wolfendale, A. W. and Worrall, D. M. (1976) Mon. Not. R. Astr. Soc. 175, 23P.

28. Worrall, D. M. and Strong, A. W. (1977) preprint.

29. Felten, J. E. and Morrison, P. (1966) Ap. J. 146, 686.

30. Fichtel, C. E., Hartman, R. C., Kniffen, D. A., Thompson, D. J., Bignami, G. F., Ögelman, H., Özel, M. E. and Tümer, T. (1975) Ap. J. 198, 163.

31. Rocchia, R., Ducros, R. and Goffet, B. (1976) Ap. J. 209, 350.

32. Page, D. N. and Hawking, S. W. (1976) Ap. J. 206, 1.

33. Stecker, F. W. (1969) Ap. J. 157, 507.

34. Montmerle, T. (1977) Ap. J. in press.

35. Sunyaev, R. A. (1974) Confrontation of Cosmological Theories with Observational Data ed. M. S. Longair (Dordrecht: Reidel) p. 167.

36. Illiaronov, A. F. and Sunyaev, R. A. (1972) Astron. Zh. 49, 58.

37. Aldrovandi, R., Caser, S., Omnes, R. and Puget, J. L. (1973) Astron. and Ap. 28, 253.

38. Ramani, A. and Puget, J. L. (1976) Astron. and Ap. 51, 411.

39. Aldrovandi, R. and D'Olival, J. B. S. (1976) Ap. and Space Sci. 44, 471.

40. Stecker, F. W. and Puget, J. L. (1973) in Gamma Ray Astrophysics ed. F. W. Stecker and J. I. Trombka, NASA SP-339 (Washington: U.S. Gov't. Printing Office) p. 381.

41. Jones, B. J. T. and Steigman, G. (1976) in preparation.

42. Field, G. B. and Perrenod, S. C. (1977) Ap. J. in press.

43. Leroy, B., Nicolle, J. P. and Schatzman, E. (1973) in Gamma Ray Astrophysics ed. F. W. Stecker and J. I. Trombka, NASA SP-339 (Washington: U.S. Gov't. Printing Office) p. 351.

44. Combes, F., Fassi-Fehri, O., and Leroy, B. (1975) Ap. and Space Sci. 37, 151.

45. Wagoner, R. V., Fowler, W. A. and Hoyle, F. (1967) Ap. J. 148, 3.

46. Burbidge, E. M., and Burbidge, G. R. (1975) in HII Regions and Related Topics ed. T. L. Wilson and D. Downes (Berlin: Springer-Verlag).

47. Gaisser, T. K. and Levy, E. H. (1974) Phys. Rev. D10, 1731.

48. Hagstrom, R. (1977) Phys. Rev. Lett. 38, 729.

49. Rees, M. J. (1974) in Confrontation of Cosmological Theories with Observational Data, ed. M. S. Longair (Dordrecht: Reidel) p. 359.