(NASA-TM-84006) OBSERVATIONAL TESTS OF BARYON SYMMETRIC COSMOLOGY (NASA) 9 p HC A02/MF A01 CSCL 03A
N83-10996
Unclas
G3/89 35289

NASA

Technical Memorandum 84006

Observational Tests of Baryon Symmetric Cosmology

F.W. Stecker

SEPTEMBER 1982

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

OBSERVATIONAL TESTS OF BARYON SYMMETRIC COSMOLOGY*

F. W. Stecker, Laboratory for High Energy Astrophysics
NASA/Goddard Space Flight Center, Greenbelt, MD. 20771,
U.S.A.

To the gods alone belongs it never to be old or die. But all things else melt with all-powerful time....

Sophocles

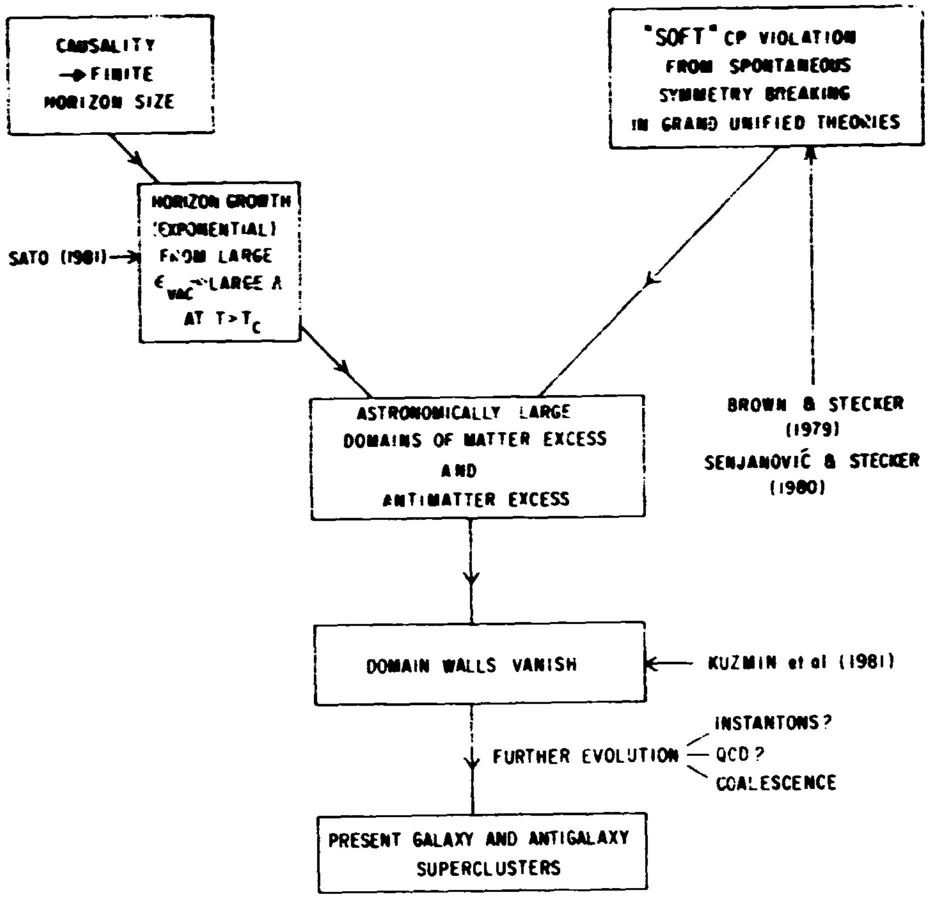
1. INTRODUCTION

With the advent of grand unified theories (GUTs) has come the concept (among others) that baryons (protons, etc.) can decay by changing into leptons ("Diamonds are not forever.") and vice versa, baryonic matter can be created from the thermal blackbody radiation in the early universe (provided, of course, that the hot big-bang model is basically correct). Using this concept, models have been suggested to generate a universal baryon asymmetry, with the consequence that no important amount of antimatter would be left in the universe at the present time (see, e.g. Langacker 1981 and references therein). These models have been motivated by observational constraints on antimatter, at least in our little corner of the universe (Steigman 1976). However, some of these constraints have been shown to be overrestrictive (Stecker 1978, Allen 1981) and an alternative model, also based on GUTs, has been suggested which maintains matter-antimatter (i.e., baryon) symmetry on a universal scale, but results in separate "fossil domains" of clusters of matter galaxies and clusters of antimatter galaxies. The basic physics argument regarding the choice between a baryon symmetric and an asymmetric cosmology hinges on the manner in which CP violation occurs in nature (or GUTs) at the temperature when the matter (antimatter) excesses are produced from the blackbody radiation. If the CP violation is spontaneous, it will arise with random sign changes in causally independent regions (Brown and Stecker 1979, Senjanović and Stecker 1980) leading to separate regions of matter and antimatter excesses. The creation of these excesses subsequent to a de Sitter phase arising from a GUT first order phase transition can result in fossil domains of astronomically

*Invited Paper presented at International Astronomical Union Symposium No. 104 on the Early Evolution of the Universe and its Present Structure, Kolymbari, Crete, Greece, Aug.-Sept. 1982. To be published in the Proceedings (ed. G.O. Abell and G.L. Chincarini) Reidel Pub. Co.

relevant size (Sato 1981). The general scenario is shown in Fig. 1. Details of the theory have been discussed and reviewed by the author recently (Stecker 1981, 1982). I will concentrate here on possible observational clues that large amounts of antimatter exist elsewhere in the universe.

SIMPLEST BARYON SYMMETRIC BIG-BANG SCENARIO



2. THE COSMIC γ-RAY BACKGROUND RADIATION

One of the most significant consequences of baryon symmetric big-bang cosmology lies in the prediction of an observable cosmic background of γ-radiation from the decay of π^0-mesons produced in nucleon-antinucleon annihilations. This is also a most encouraging aspect of this cosmology, since it satisfactorily explains the observed energy spectrum of the cosmic background γ-radiation as no other proposed mechanism does (with the possible exception of hypothetical point sources).

For high redshifts z, when pair production and Compton scattering become important, it becomes necessary to solve a cosmological photon transport equation in order to calculate the γ-

ray background spectrum. This integro-differential equation takes account of γ-ray production, absorption, scattering, and redshifting and is of the form

$$\frac{\partial \mathcal{I}}{\partial t} + \frac{\partial}{\partial E}\left[-EH(z)\mathcal{I}\right] = \mathcal{Q}(E,z) - \kappa_{AB}(E,z) + \int_{E}^{\epsilon(E)} dE'\, \kappa_{sc}(E,z)\, \mathcal{I}(E;\, E')\, dE' \qquad (1)$$

where

$$\mathcal{I}(E,z) \equiv (1+z)^{-3}\, I(E,z)$$

$$\mathcal{Q}(E,z) \equiv (1+z)^{-3}\, Q(E,z)$$

and

$$\frac{\partial \mathcal{I}}{\partial t} = -\,(1+z)\, H\,(z)\, \frac{\partial \mathcal{I}}{\partial z}\,,$$

$$H(z) = H_o(1+z)\,(1+\Omega z)^{1/2}$$

The second term in eq. (1) expresses energy loss from the redshift effect. The third term is the γ-ray source term from $p\bar{p}$ annihilation primarily into π^os. The absorption term is from pion production and Compton interactions with electrons at high z and the scattering integral puts back Compton scattered γ-rays at lower energies E<E'.

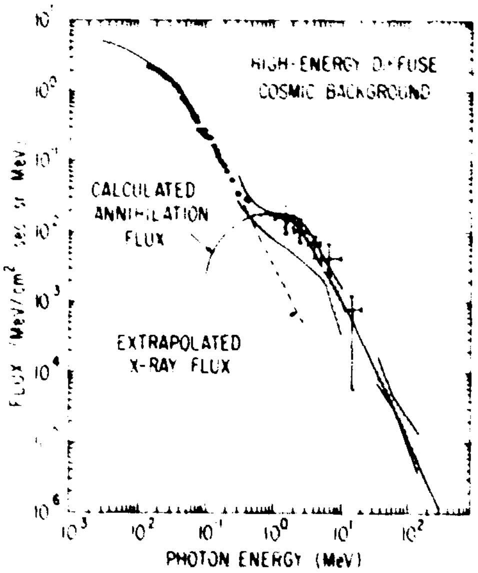


Fig. 2. The Cosmic γ-Ray Background Spectrum: Theory and Observational Data.

Fig. 2 shows the observational data on the γ-ray background spectrum. The dashed line is an extrapolation of the X-ray background component. The calculated annihilation spectrum (Stecker 1978) is also shown. The excellent agreement between the theory and the data is apparent. Other attempts to account for the γ-ray background radiation spectrum by diffuse processes give spectra which are inconsistent with the observations, generally by being too flat at the higher energies.

In Fig. 2 the spectrum is shown as an energy flux. The "bump" in the energy range of 1-10 MeV stands out clearly and can be used as <u>prima facie</u> evidence that a new spectral component dominates in this region. To illustrate this quantitatively, one may note that the energy flux in the 10-100 keV

X-ray background is $\sim 2 \times 10^{-5}$ erg cm^{-2} s^{-1} sr^{-1}. Using the same units, a power law extrapolation of the X-ray component, as shown in the figure, would give an energy flux of only $\sim 5 \times 10^{-9}$ in the 1-10 MeV range whereas the observed flux in this range is $\sim 2 \times 10^{-7}$, a factor of ~ 40 higher! The observational data, in order of increasing energy, are from Marshall, et al. (1980), Rothschild, et al. (1982), Trombka, et al. (1977), Schönfelder, et al. (1980) and Fichtel et al. (1978). (The data of Fichtel, et al. contain a component of galactic γ-radiation which causes a flattening at the higher energies.)

It is possible that the γ-ray background is made up of a superposition of point sources. However, since only one extragalactic source has been seen at energies above ~ 1 MeV, this remains a conjecture. Such a hypothesis must be tested by determining the spectral characteristics of extragalactic sources and comparing them in detail with the characteristics of the background spectrum. It presently appears, e.g., that Seyfert galaxies may have a characteristic spectrum which cuts off above a few MeV, so that they could not account for the flux observed at higher energies.

3. ANTIMATTER IN THE COSMIC RADIATION

Measurements of cosmic-ray antiprotons can give us important information about cosmic-ray propagation and also provide a test for primary cosmological antimatter. Buffington, et al. (1981), observing at energies well below the secondary cutoff, appear to see a signal of primary antiprotons. Data on $\bar{p}$ fluxes at higher energies (Bogomolov, et al. 1979, Golden, et al. 1979) give measured values a factor of 4-10 above the fluxes expected for a standard "leaky box" type propagation model with the primaries passing through ~ 5 g/cm^2 of material (Stecker, et al. 1981 and references therein). In fact, the $\bar{p}$ flux integrated over the observed energy range is ~ 7 times the expected flux. But what is particularly striking is that the flux observed by Buffington, et al. (1981) in the 150-300 MeV range is orders of magnitude above what is expected (see Fig. 3).

The reason that standard secondary $\bar{p}$ production models give a very low flux in the 150-300 MeV energy range is easily understood and is a basic feature of the relativistic kinematics (Gaisser and Levy 1974), viz., antiprotons with less that ~ 1 GeV energy must be produced backward in the cms of the collision, and those with energy as low as 150-300 MeV must be produced by cosmic-ray protons significantly above threshold. Since the cosmic-ray proton energy spectrum falls off steeply with energy, the secondary $\bar{p}$ flux has a natural low-energy cutoff. This leaves two explanations for the cosmic-ray $\bar{p}$'s: (1) they are primary, or (2) they are secondary and have undergone significant deceleration. For case (1) we would expect that the $\bar{p}/p$ is independent of energy as observed ($\bar{p}/p = (3.2 \pm 0.7) \times 10^{-4}$), consistent with the primary hypothesis.

It can be easily demonstrated that solar modulation effects will not produce the deceleration required by the secondary hypothesis to

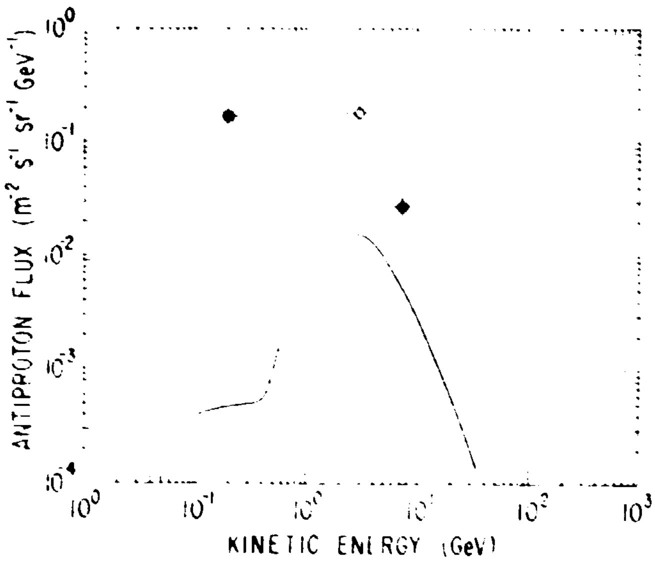


Fig. 3. Cosmic ray antiproton fluxes: Data and predictions from the standard propagation model with energy losses (Protheroe 1982).

account for the 150-300 MeV flux (Stecker, et al. 1981). Stecker et al. (1981, 1982) have argued that an extragalactic primary flux from antimatter active galaxies could supply a $\bar{p}$ flux with a ratio $\bar{p}/p \sim 5 \times 10^{-4}$, the protons being overwhelmingly galactic in origin (Stecker 1975). They have further argued that the lack of cosmic-ray $\bar{\alpha}$'s at present detection levels can plausibly be accounted for by spallation and photodisintegration in the core of these sources. They estimate spallation and photodisintegration times of $\tau_{sp} \sim 0.2 - 6 \times 10^4$ yr and $\tau_{pd} \sim 3 \times 10^8$ yr in these sources. Finally, it is predicted that the $\bar{\alpha}/\alpha$ ratio should be determined by $\bar{\alpha}$ acceleration in normal antimatter galaxies and that the resultant flux should be in the range $5\times10^{-6} \lesssim \bar{\alpha}/\alpha \lesssim 5\times10^{-5}$. It is also estimated that extragalactic cosmic-rays can reach us by diffusion from distances of up to 500 Mpc (Stecker, et al. 1982).

Other possible explanations for the cosmic-ray $\bar{p}$ flux have recently been reviewed by Protheroe (1982). These alternatives appear to have serious problems. Production of $\bar{p}$'s through $n-\bar{n}$ oscillations gives a flux orders of of magnitude below the observed flux (at best). Galactic primordial black holes are quite ad hoc. Suggestions for secondary generation and deceleration of $\bar{p}$'s in galactic cosmic-ray sources have energetics problems.

4. FUTURE TESTS

We have seen how the γ-ray and cosmic-ray $\bar{p}$ observations can be accounted for by a baryon symmetric cosmology. We have also seen how measurements of $\bar{\alpha}$'s in the cosmic radiation can provide a future test. Suggestions to look for $\overline{Fe}$ have also been made recently (Ahlen, et al. 1982).

Several suggestions have been made for using high-energy neutrino astronomy to look for antimatter elsewhere in the universe (Learned and Stecker 1980; Berezinsky and Ginzberg 1981, Brown and

Stecker (1982). These suggestions are all based on the fact that cosmic ray pp and $p\gamma$ interactions favor the secondary production on π^+'s over π^-'s, whereas for $\bar{p}\bar{p}$ and $\bar{p}\gamma$ interactions the situation is reversed. The subsequent decay of the pions results in equal amounts of ν_μ's and $\bar{\nu}_\mu$'s of almost equal energies. However, π^+ decay leads to ν_e production, whereas π^- decay leads to $\bar{\nu}_e$ production. A production mechanism of particular importance in this context because of its large inherent charge asymmetry, involves the photoproduction of charged pions by ultrahigh energy cosmic rays interacting with the universal 3K blackbody background radiation. The most significant reactions occur in the astrophysical context principally through the Δ resonance channel.

There is a significant and potentially useful way of distinguishing ν_e's from $\bar{\nu}_e$'s, namely through their interactions with electrons. The $\bar{\nu}_e$'s have an enhanced cross section (resonance) through formation of weak intermediate vector bosons such as the W^-. For electrons at rest in the observer's system, the resonance occurs for cosmic $\bar{\nu}_e$'s of energy $M_W^2/2m_e = 6.3 \times 10^3$ TeV for $M_W \simeq 80$ GeV.

The cosmic and atmospheric fluxes for $\bar{\nu}_e$'s based on cosmic ray production calculations have been given by Stecker (1979). Assuming that there is no significant enhancement in the flux from production at high redshifts, the integral $\bar{\nu}_e$ spectrum from $\gamma\bar{p}$ interactions is expected to be roughly constant at 10^{-18} to 10^{-17} $\bar{\nu}_e$'s cm^{-2} sr^{-1} up to an energy of $\sim 2 \times 10^7$ TeV, above which it is expected to drop steeply. It is expected that the largest competing background flux of $\bar{\nu}_e$'s will be prompt $\bar{\nu}_e$'s from the decay of atmospherically produced charmed mesons. A cosmic $\bar{\nu}_e$ signal may be heavily contaminated by prompt atmospheric $\bar{\nu}_e$'s at the W resonance energy. The cosmic flux is expected to dominate the higher energies so that the existence of higher mass bosons B^- may be critical to any proposed test for cosmic antimatter using diffuse fluxes (Brown and Stecker 1982). An acoustic deep underwater neutrino detector may provide the best hope for testing for cosmic antimatter by studying the diffuse background neutrinos. The practical threshold for such devices appears to be in the neighborhood of $10^3 - 10^4$ TeV (Bowen and Learned 1979). One gains much in looking for higher mass resonances at higher energies. Acoustic detectors of effective volume $\gg 10$ km^3 (10^{10} tons) may be economically feasible and event rates of $\sim 10^2 - 10^4$ yr^{-1} may be attained in time.

Indirect future observational tests involve studies of primordial He (Stecker 1980) and distortions in the high frequency side of the microwave background radiation (Stecker and Puget 1973). Observation of angular fluctuations in the 100 MeV γ-ray background radiation using the Gamma Ray Observatory satellite could play a key role in determining whether the flux is from point sources or more diffuse "ridges" as predicted by baryon symmetric cosmology.

There is an intriguing connection between the "cell structure" of galaxy clustering presented in many papers at this symposium and the large scale fossil domain structure predicted by our baryon symmetric cosmology. It is obvious that future theoretical studies exploring this relationship could be of significant value.

5. REFERENCES

Ahlen, S. P., Prince, P. B., Salamon, M. H. and Tarlé, G., 1982, Astrophys. J. 260, 20.

Allen, A. J., 1981, Mon. Not. R. Astron. Soc. 197, 679.

Bogomolov, E. A., et al., 1978, Proc. 16th Intl. Cosmic Ray Conf., Kyoto 1, 330.

Bowen, T. and Learned, J. G., 1979, Proc. 16th Intl, Cosmic Ray Conf., Kyoto 10, 386.

Brown, R. W. and Stecker, F. W., 1979, Phys. Rev. Lett. 43, 315.

Brown, R. W. and Stecker, F. W., 1982, Phys. Rev. D26, 373.

Buffington, A., Schindler, S. M. and Pennypacker, C. R., 1981, Astrophys. J. 248, 1179.

Fichtel, C. E., Simpson, G. A., and Thompson, D. J., 1978, Astrophys. J. 222, 833.

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

Golden, R. L., et al., 1979, Phys. Rev. Lett. 43, 1196.

Kuzmin, V. A. et al., 1981, Phys. Lett. 105B, 167.

Langacker, P., 1981, Phys. Rpts. 72, 185.

Learned, J. G. and Stecker, F.W., 1980, Proc. Neutrino 79 Intl. Conf., Bergen Norway (ed. Haatuft, A. and Jarlskog, C.) 2, 461.

Marshall, et al., 1980, Astrophys. J. 235, 4.

Protheroe, R. J. 1982, in Proc. NATO Adv. Study Inst., Erice, Italy, Reidel Pub. Co., Dordrecht, in press.

Rothschild, R. E., et al., 1982, UCSD SP-82-23, to be published.

Sato, K., 1981, Phys. Lett. 99B, 66.

Schönfelder, V., et al., 1980, Astrophys. J. 240, 350.

Senjanovic, G. and Stecker, F. W., 1980, Phys. Lett., 96B, 285.

Stecker, F. W., 1975, Phys. Rev. Lett. 35, 188.

Stecker, F. W., 1978, Nature 273, 493.

Stecker, F. W., 1979, Astrophys. J. 228, 919.

Stecker, F. W., 1980, Phys. Rev. Lett. 44, 1237.

Stecker, F. W., 1981, Proc. Tenth Texas Symp. on Relativistic Astrophys. Ann. N.Y. Acad. Sci. 375, 69.

Stecker, F. W., 1982, Proc. 1981 Oxford Intl. Symp. on Progress in Cosmology (ed. A. W. Wolfendale), Reidel Pub. Co., Dordrecht, 1.

Stecker, F. W., Protheroe, R. J. and Kazanas, D., 1981, Proc. 17th Intl. Cosmic Ray Conf., Paris 9, 211.

Stecker, F. W., Protheroe, R. J. and Kazanas, D., 1982, to be published.

Stecker, F. W. and Puget, J. L., 1973, in Gamma Ray Astrophysics (ed. F. W. Stecker and J. I. Trombka) U. S. Gov't. Printing Off., Washington, 381.

Steigman, G., 1976, Ann. Rev. Astron. Astrophys. 14, 339.

Trombka, J. I., et al., 1977, Astrophys. J. 212, 925.