ANTIPARTICLES IN THE EXTRAGALACTIC COSMIC RADIATION

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ABSTRACT

It may be possible to account for a previously puzzling feature - a "bump" in the energy range 10^{14}-10^{15} eV - of the cosmic ray spectrum by hypothesizing a primary extragalactic origin for the bulk of the observed cosmic ray antiprotons, although such an explanation is not unique. In this model, most of the cosmic rays above 10^{15} eV are extragalactic. We describe a method of testing this hypothesis experimentally.

1. Introduction. One of the most fundamental questions in cosmology is the question of the existence of antimatter in significant quantities in the universe. Does antimatter play an equal role with matter in the makeup of the galaxies? This question has now become a question of fundamental importance to physics as well. In the contemporary paradigm of grand unified gauge theories it is related to the question of the nature of CP violation at high energies (1,2). Recent theoretical work based on the concepts of grand unified theories has resulted in the development of a plausible baryon-antibaryon domain theory in which matter and antimatter are created in separate regions of survivable size to begin with (3-5). Various observational aspects of this theory have been previously discussed (6,7) and the subject of baryon symmetric cosmology has been recently reviewed elsewhere (8,9).

2. Primary Antimatter. The present status of cosmic ray antiproton measurements and the attempts to understand them have been recently reviewed (10) and an exegesis of the primary extragalactic origin hypothesis has also been recently given (11). We will discuss further implications of potential basic import to cosmic ray research here and we will also propose an experimental search program based on these considerations. We start with the hypothesis that the baryon symmetric domain cosmology leads to a flux of extragalactic cosmic rays consisting of roughly equal amounts of protons and antiprotons with the sources of these cosmic rays being primarily active galaxies (12) and with helium and antihelium nuclei being supressed by destruction processes in these sources (11). We assume that the galactic wind is too weak to keep out the extragalactic cosmic radiation. Observations favor the interpretation that the galactic wind is in reality a "breeze" (13).

The measured spectrum of cosmic radiation can be represented by a power law in energy of the form $KE^{-\Gamma}$ with the spectral index $\Gamma \simeq 2.75$ for several decades above the 10 GeV energy level. It appears likely that this radiation is produced primarily in galactic sources (14,15). Furthermore, the source spectrum of this radiation is expected to have a lower spectral index Γ_s than that observed at the earth which has been steepened by energy dependent propagation effects. A value for Γ_s of approximately 2.0 to 2.2 appears to be likely for two reasons. (A) Measurements of the ratio of secondary to primary nuclei in the cosmic radiation suggest that the mean lifetime in the Galaxy owing to trapping by the tangled galactic magnetic fields falls with energy as $E^{-\delta}$ where the most recently derived value (16) of $\delta \simeq 0.7$. (B) The theoretical shock acceleration models for cosmic ray production currently favored (17) generally yield production spectra with Γ_s close to 2.

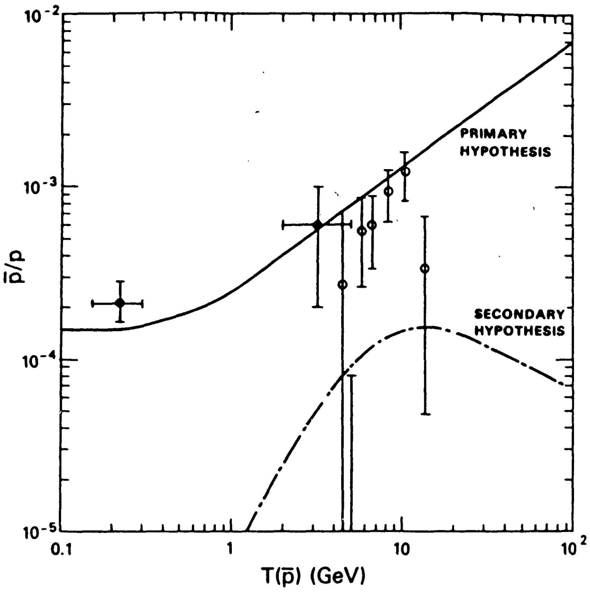
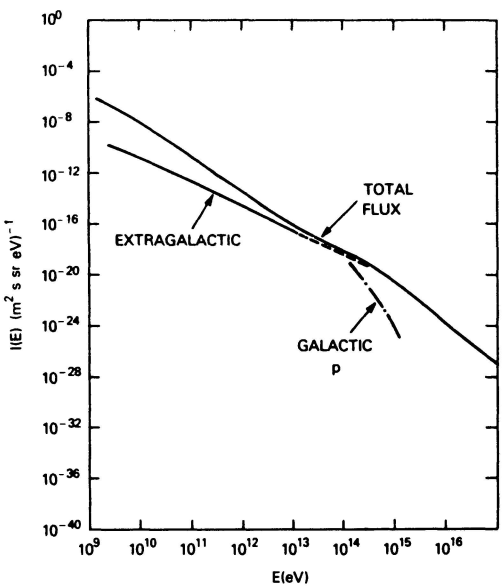


Figure 1. Observations and theoretical p̄/p ratios as a function of kinetic energy. The data points are from Refs.(18-20). The theoretical curves take account of solar modulation effects.

If we assume that there exists a general acceleration mechanism for generating cosmic rays which acts in both galactic and extra-galactic sources to give a universal source spectrum with $\Gamma_s \simeq 2$, as is now thought to be the case with shock acceleration, then the extragalactic cosmic ray component should reflect this source spectrum. Thus, with the antiprotons assumed to be both primary and extragalactic and the bulk of the protons to be galactic, the expected ratio of antiprotons to protons should increase with energy as E^{δ}.

Taking $\delta \simeq 0.7$, antiprotons could make up approximately one per cent of the cosmic ray flux at an energy of $\simeq$ 500 GeV and even ~ 50 per cent at higher energies. This has important observational implications (see section 3). The situation is indicated in Figure 1 which shows the present data on p̄/p ratios as a function of kinetic energy and the theoretical curve corresponding to a primary extragalactic antiproton flux. Solar modulation flattens the theoretical curve at low energies. Additional secondary production of antiprotons (as shown) is relatively unimportant. It can be seen that the theoretical curve for the extragalactic primary origin hypothesis provides an encouragingly good fit to the present p̄ data. Thus, our hypothesis has possible observational support.

Figure 2 shows the effect of extrapolating the extragalactic intensity of both protons and antiprotons (this introduces a factor of two) with a spectral index of 2 to higher energies and superposing it on the galactic cosmic ray spectrum with index $\Gamma \simeq 2.75$. Note that such an extrapolation implies that the extragalactic and galactic cosmic ray fluxes become comparable at an energy of about 10^5 GeV and that extragalactic particles predominate above this energy. It is interesting that the resultant flattening in the spectrum occurs at this particular energy where there have been claims (22) of a flattening in the cosmic ray spectrum as inferred from measurements of extensive air showers. A steepening in the spectra of both the galactic and extragalactic components would be required by the observations for energies above 10^6 GeV.



3. Experimental Tests. Since our model indicates that the antiproton-to-proton ratio which should increase with energy, measurements of the sign of the charges of cosmic rays at the highest practical energy and the determination of the spectra of the various charged components of the cosmic radiation up to that energy will provide a test of our hypothesis as well as the black hole hypothesis (21) and the photino hypothesis (Cf. Fig. 1 here with Fig. 2 of paper OG 6.1-9). Such a test requires the placement of the experiment above the atmosphere so that the incoming cosmic ray nuclei can be measured directly. Furthermore, the sign of their charges (and magnitude) may be measured by use of a superconducting magnet. A detector of

Figure 2. The effect of extragalactic primary protons and antiprotons on the total cosmic-ray spectrum according to the model discussed in the text. It can be seen that this model may account for the putative flattening in the observed cosmic ray spectrum near 10^{14} eV.

this type, with an attainable energy of about 500 to 1000 GeV, could be flown aboard a space shuttle (23,24). In addition, an emulsion stack experiment could be flown on a high altitude balloon or on the space shuttle to look for antihelium nuclei, even at the reduced level implied by our hypothesis. A polar orbit would be desirable to avoid the geomagnetic cutoff. In view of the almost impossible odds of creating a secondary ^{4}He antinucleus, the unambiguous detection of even one such particle would provide irrefutable evidence of primary cosmic ray antimatter. (The observed low-energy antiprotons in the cosmic radiation are also quite difficult to explain as secondaries from cosmic-ray interactions.)

If the $\bar{p}/p$ ratio is observed to continue to increase as $E^{0.7}$ or thereabouts at higher energies, then our hypothesis of extragalactic antiprotons from antimatter galaxies will have very strong support. This would rule out the photino and black hole hypotheses. The observation of antihelium nuclei would, as already mentioned, provide certainty. The extent to which non-observation of antihelium disproves our hypothesis is unclear, but if $\bar{\alpha}/\alpha \ll 10^{-5}$ (the value expected very approximately on the basis of $\bar{\alpha}$'s leaking from "normal" antimatter galaxies) then the difficulty would be severe.

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