Cosmic-ray electrons in the closed-galaxy model

G. D. Badhwar and S. A. Stephens*
National Aeronautics and Space Administration, Johnson Space Center, Houston, Texas 77058
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We have examined the consequences of the "closed galaxy" cosmic-ray confinement model of Rasmussen and Peters with regard to the electron component of cosmic rays. It is found that the predictions of this model are inconsistent with the observed intensity and charge composition of electrons. The model is also inconsistent with the galactic radio emission.

INTRODUCTION

Rasmussen and Peters[1] have recently proposed an "equilibrium plus local source" model which explains the chemical composition of the observed cosmic rays. In this model, the cosmic-ray sources inject only α-particle-type nuclei and these are *totally* confined in the galaxy. These nuclei spallate in the interstellar medium and yield all of the observed hydrogen nuclei while most of the heavier nuclei come from a local source. In this paper we examine the predictions of this model on the electron component of the cosmic rays.

CALCULATION OF POSITRON SPECTRA

In the Rasmussen-Peters model, the mean lifetime of nucleons is essentially determined by the attenuation mean free path of protons in the interstellar medium, and the mean intensity of cosmic-ray nucleons in the galaxy would be the same as the observed cosmic-ray nuclei minus the local source contribution, which is only about 12% of the total nucleons. Extensive calculations on the production of secondary electrons in the interstellar space have been made in the past. We have, in a separate paper,[2] calculated the production spectrum of secondary electrons and positrons from 1 MeV to 100 GeV, using the latest available production cross sections of $\pi^\pm$, $K^\pm$, and K^0, and a cosmic-ray proton spectrum of the form[3] $J(E) = (2\times 10^4)E^{-2.75}$ protons/(m^{2}sr sec GeV), where E is the total energy per nucleon. The spectral shape for the $Z \geq 2$ components was assumed to be the same as that of the proton spectrum. Using this production spectrum we have evaluated the equilibrium spectrum of the secondary positrons for various values of the mean density, N_H, of the interstellar medium by taking into account all energy-loss processes, namely, ionization, bremsstrahlung, synchrotron radiation, and the inverse Compton scattering.[4,5] The positron spectra are shown in Fig. 1 by solid curves for $N_H = 1$ atom cm^{-3} (curve A), $N_H = 0.2$ atom cm^{-3} (curve B), and $N_H = 0.1$ atom cm^{-3} (curve C). The dashed curve in this figure is the modulated spectrum obtained for the curve C using the exact solution of the Fokker-Planck equation[6] with the same constants that fit both the proton and helium spectra at solar minimum. For comparison the available flux values,[7-9] which fall below the calculated spectrum are plotted. Thus, even for $N_H = 0.1$ atom cm^{-3}, the pre-

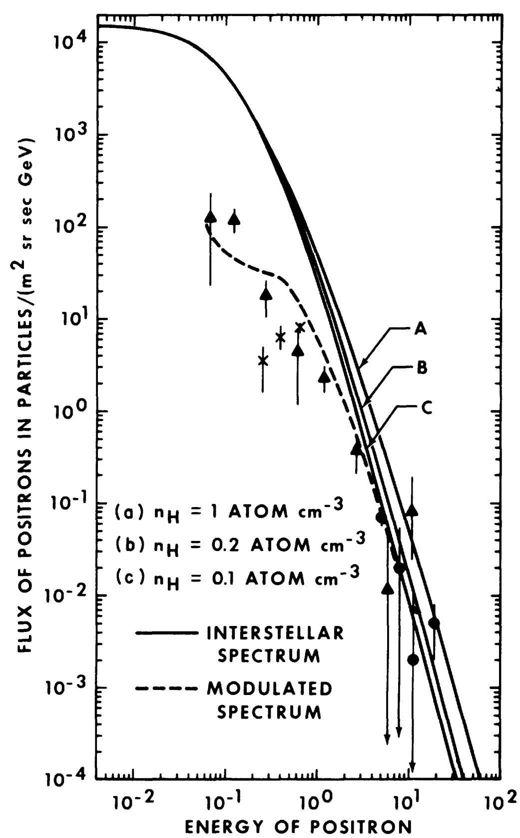

FIG. 1. The calculated positron flux in interstellar space is shown as a function of positron energy in GeV by the solid curves for different values of the gas density. The modulated spectrum shown by the dashed curve is for $N_H = 0.1$ atom cm^{-3}. The data points are taken from: ▲ Fanselow *et al*. (Ref. 7), ● Buffington *et al*. (Ref. 8), and × Hartman and Pellerin (Ref. 9).

dictions of this model for the positron flux in the energy interval of 200 MeV to 2 GeV are higher than indicated by the observations. This discrepancy increases with increasing value of N_H. On the other hand, for $N_H < 0.1$ atom cm^{-3} the calculated positron intensity above a few GeV falls below the observations. The spectral indices of the modulated positron energy spectrum for which the above discrepancy is smallest ($N_H = 0.1$ atom cm^{-3}) are 3.2 ($1 \le E \le 30$ GeV) and 3.5 ($5 \le E \le 30$ GeV) while the observed values are 2.6 ± 0.5, by Fanselow *et al.*,[7] and $2.7 \pm .4$, by Buffington *et al.*,[8] in the corresponding energy region.

CALCULATION OF THE RADIO SPECTRA

We next examine the nonthermal galactic radio emission that would result from the cosmic-ray electrons, while spiralling in the interstellar magnetic field.[5] We first *assume* that in the Rasmussen-Peters model the cosmic-ray electrons are purely secondary, just like the protons. The calculated radio spectra using the total $(e^+ + e^-)$ equilibrium secondary electrons towards the anticenter direction in the galaxy are shown by solid curves (Curves A–D) in the lower part of Fig. 2, for various values of gas density, N_H, and magnetic field strength, B. The data points shown in this figure are those compiled by Daniel and Stephens[5] in the frequency range of 5 to 600 MHz. One observes that the calculated curves are much steeper than the observed spectra, and the spectral difference increases with decreasing interstellar gas density, N_H. This rules out the possibility that, in this model, the cosmic-ray electrons are purely secondary in origin. This conclusion is further substantiated by the observed charge composition of electrons.

Therefore, in order to explain the observed radio spectrum, there should exist another component of electrons, the *sources of which cannot be local*, but have to be distributed over the entire galaxy. We have attempted to deduce the spectrum of this nonlocal component from the observed radio spectrum.

One finds from Fig. 2 that for interstellar gas density between 0.1 atom cm^{-3} and 1.0 atom cm^{-3}, the radio emission from purely secondary electrons at frequencies below 10 MHz exceeds the observed radio flux for a magnetic field strength of 4 μG or greater. The dashed curve in Fig. 2 is the fitted radio spectrum for the total electron spectrum (secondary + nonlocal source) for three possible cases, namely $N_H = 0.1$ atom cm^{-3} with $B_\perp = 3$ or 4 μG and $N_H = 1$ atom cm^{-3} with $B_\perp = 3$ μG. It is found that the primary electron spectrum needed to obtain the above fit peaks at an energy between about 0.5 and 1 GeV and has a spectral index of about 2.6 above ~2 GeV. However, the absolute intensity of this component is at least twice the observed intensity[5] at any energy above ~1 GeV. Further, by virtue of the total confinement and the consequent energy loss, the electrons from the nonlocal source must be injected with a spectrum above ~2 GeV with spectral index of 1.6, which is considerably flatter than the assumed injection spectrum of the nucleonic component. Thus, this model would require a different acceleration mechanism for the cosmic-ray electrons than that for the nucleons.

We compare in the upper part of Fig. 2 the calculated fraction of positrons in the electron com-

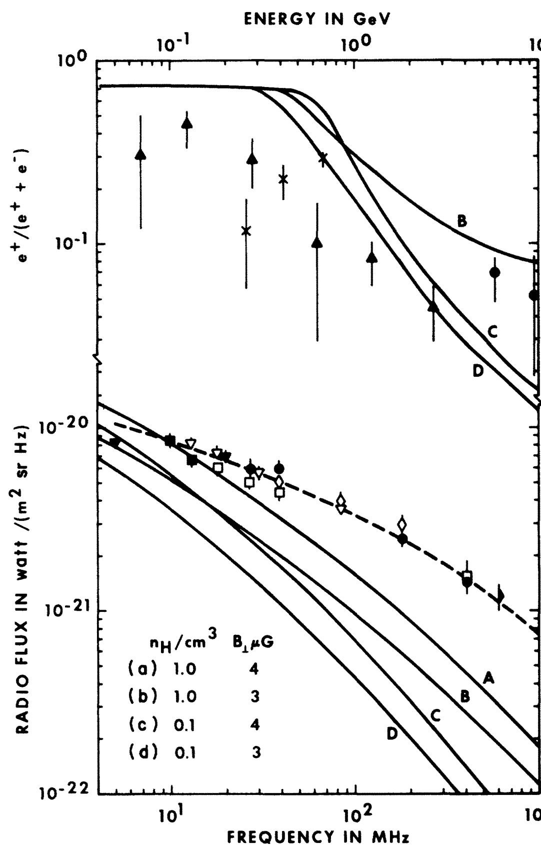

FIG. 2. The galactic radio spectrum in the direction of the anticenter is shown in the lower part of the figures. The solid curves are the calculated spectra using the equilibrium secondary electrons for various values of N_H and $B_\perp$, and the dashed curve are those spectra after including the contribution from the nonlocal electrons with curves B, C, and D. The data points in this figure are taken from the work of Daniel and Stephens (Ref. 5). In the upper part of this figure, the solid curves are the calculated fraction of positrons as a function of energy; the symbols to the data points are the same as those in Fig. 1.

ponent of the cosmic-ray electrons (which includes the directly accelerated component) with the observed data.[7-9] The curves shown in this part of the figure correspond to the same set of parameters as the curves in the lower part of this figure. It is clear from this comparison that the calculated fraction of positrons using Rasmussen-Peters model is not consistent with the observations.

CONCLUSIONS

The following disagreements exist between the Rasmussen-Peters model and the observations:

(a) The absolute flux of positrons calculated using the Rasmussen-Peters model is large compared to the observed flux.

(b) The calculated spectral index of the positron spectrum ($E \gtrsim 1$ GeV) is larger than the observed index.

(c) The absolute intensity of the primary electrons needed to explain the observed radio flux above a few GeV is at least twice the observed flux and the spectral index of this component at injection needs to be about one power flatter than that of the nucleonic components.

(d) The resulting $e^+/(e^+ + e^-)$ ratio is not in agreement with the observations.

Thus, we feel that it is difficult to accommodate the observed electron component of the cosmic radiation and the galactic radio emission in the Rasmussen-Peters "closed galaxy" model for the confinement of cosmic rays.

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[2]G. D. Badhwar and S. A. Stephens, unpublished work. The conclusions are not affected if one used, instead, the previous calculations (for references see Ref. 5).

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[7]J. L. Fanselow, R. C. Hartman, R. H. Hildebrand, and P. Meyer, Astrophys. J. 158, 771 (1969).

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