The Cosmic-Ray Electron Spectrum in a Disc-Halo Galactic Model.

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It has been shown [1-3] that the observed cosmic-ray electron spectrum [4] between 1 and 350 GeV is compatible with the existence of a universal 3 °K black-body radiation [5] if one considers electron leakage times much smaller than the currently accepted halo leakage times. In the no-halo model of O'Connell [2], the electrons leaked from the galactic disc in a time τ_d of the order of $5 \cdot 10^{13}$ s; agreement with experiment was then obtained with a spectral index γ of about 2.5 (single power-law spectrum). Ramaty and Lingenfelter [1] point out that the experimental data may be fitted by two power laws having the same spectral index but different absolute normalizations; spectral indexes ranging from 1.9 to 2.6 may be used with corresponding values of the normalization ratio ranging from 7 to 1, respectively. In addition, RL conclude that such a spectral behavior is consistent with their disc-halo model [1]. However, as we shall demonstrate, there are certain inconsistencies in the analysis of RL and it is the purpose of this letter to show that the disc-halo model is consistent only with a model for which the ratio of the absolute normalizations is very close to 1 with a resultant spectral index of about 2.5. In other words, the disc-halo model becomes practically indistinguishable from the no-halo model of O'Connell [2].

The sequence of events considered by RL is as follows: electrons are produced in the disc at a rate $q(E)$ per unit volume per second (source electrons), and after a time τ_d leak out into the halo, and become halo electrons. While the outgoing electron flux is regulated by a leakage process, once they become halo electrons they can be *freely exchanged* between disc and halo, still retaining their identity

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(1) R. Ramaty and R. E. Lingenfelter: *Phys. Rev. Lett.*, **17**, 1230 (1966), hereafter referred to as RL. We adhere to the notation of this paper except for the replacement of τ by τ_d.

(2) R. F. O'Connell: *Phys. Rev. Lett.*, **17**, 1232 (1966).

(3) R. Cowsik, Y. Pal, S. N. Tandon and R. P. Verma: *Phys. Rev. Lett.*, **17**, 1298 (1966).

(4) R. R. Daniel and S. A. Stephens: *Phys. Rev. Lett.*, **17**, 935 (1966).

(5) A. A. Penzias and R. W. Wilson: *Astrophys. Journ.*, **142**, 419 (1965); R. Dicke, P. J. E. Peebles, P. G. Roll and D. J. Wilkinson: *Astrophys. Journ.*, **142**, 414 (1965); P. G. Roll and D. J. Wilkinson: *Phys. Rev. Lett.*, **16**, 414 (1966); G. B. Field and J. L. Hitchcock: *Phys. Rev. Lett.*, **16**, 817 (1966); *Astrophys. Journ.*, **146**, 1 (1966); P. Thaddeus and J. F. Clauser: *Phys. Rev. Lett.*, **16**, 819 (1966); T. F. Howell and J. R. Shakeshaft: *Nature*, **210**, 1318 (1966).

as halo electrons, and without undergoing any additional leaking process either on they way in or out of the disc. As a consequence of this, a halo electron may spend more time in the disc than a source electron. (Taking for example, as RL, a γ of 2.1 and the corresponding normalization ratio of 4.5, and noting eq. (3) as well as the following paragraph of RL, one finds that a halo electron stays 3.5 times longer in the disc than a source electron.)

We have two main objections to this approach. In the first place, RL fix a tag to the source and to the halo electrons, and expect them to behave differently even when they are in the same place and have the same energy. Secondly, the free-exchangeability assumption implies that a halo electron will much more readily leak back into the disc than into interstellar space. As will be apparent below, this is not correct.

In reformulating the disc-halo approach to the problem, we will consider that the disc and halo are entirely *separate* entities and the exchange of electrons between them can only occur through leakage processes. Moreover, once an electron is in the disc, it behaves irrespective of whether it was produced by the source or leaked back from the halo.

Now all electrons which leak from the disc go into the halo but only a fraction, x say, of the electrons which leak from the halo goes into the disc (the rest, of course, goes into intergalactic space). Thus we have

$$\frac{n_d}{\tau_d} = q + x\frac{n_h}{\tau_h}\frac{v_h}{v_d}, \quad \text{for } E < E_1, \tag{1}$$

$$\frac{n_h}{\tau_h} = \frac{n_d}{\tau_d}\frac{v_d}{v_h}, \qquad \text{for } E < E_2, \tag{2}$$

and

$$\frac{n_h}{\tau_h} = E^{-(\gamma-1)} \sim 0\,, \quad \text{for } E_2 < E\,. \tag{3}$$

Therefore

$$\frac{n_d}{\tau_d} = \begin{cases} q(1-x)^{-1}, & \text{for } E_1 < E_2 < E, \\ q, & \text{for } E_2 < E < E_1, \end{cases} \tag{4}$$

so that the normalization ratio, A say, is equal to $(1-x)^{-1}$. Now x depends essentially on the ratio of the surface area at the interface of the halo and disc to the sum of the surface areas at the interface of the halo and intergalactic space and the interface of the halo and disc. Thus [*]

$$A \simeq \left\{1 - \frac{1}{2}\left(\frac{R_d}{R_h}\right)^2\left(1+\frac{h_d}{R_d}\right)\left[1+\frac{1}{2}\left(\frac{R_d}{R_h}\right)^2\left(1+\frac{h_d}{R_d}\right)\right]^{-1}\right\}^{-1}. \tag{5}$$

where $R_{d,h}$ refer to the radii of the disc and halo, respectively, and h_d is the thickness of the disc.

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[*] Apart from the geometric factor, an electron in the halo will probably find it harder to leak to the disc than to leak into the intergalactic space, due to magnetic-field considerations. This will have the effect of reducing x from what it would be from the pure geometric factor and thereby strengthen our subsequent arguments.

It is important to note that the ratio τ_h/τ_d does not appear in our expression for A, in contrast to the result of RL, *viz.* $A(\text{RL}) = 1 + v_d\tau/v_h\tau_d$. For values of $R_{d,h}$ and h_d equal to 15 kpc, 20 kpc and 0.5 kpc, respectively (7), we obtain a value of A equal to 1.3. Therefore the disc-halo model leads to a normalization ratio not much different from unity with the result that the spectral index must be of the order of 2.5 to give agreement with experimental results. In summary, we see that the disc-halo model cannot lead to a substantial break in the cosmic-ray electron spectrum at a critical energy of about 6 GeV, in contrast to the conclusion drawn by RAMATY and LINGENFELTER, and consequently, within the framework of this model, the data can only be fitted with values of γ of about 2.5.

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(7) J. L. STEINBERG and J. LEQUEUX: *Radio Astronomy* (New York, 1963), p. 174.