HIGH-ENERGY PRIMARY ELECTRONS AND THE UNIVERSAL BLACKBODY RADIATION*

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We show that in the framework of the galactic-halo model, the recent measurements of the electron energy spectrum in the 1- to 350-GeV energy interval are compatible with the presence of a universal blackbody radiation (~3.5°K). The lifetime of the halo electrons is estimated to be $(1.5\text{-}3)\times10^{15}$ sec.

The energy spectrum of primary cosmic-ray electrons has by now been determined by a number of experiments over a wide range of energies.[1-9] In the 0.05- to 10-GeV energy interval,[10-12] a negative excess of electrons has been observed. Daniel and Stephens have recently reported results for the electron spectrum in the energy region from 12 to 350 GeV,[1,2] and for the fraction of positrons in the electron component at energies $\gtrsim$12 GeV by E-W asymmetry measurements. Combining their results with data at lower energies, Daniel and Stephens conclude that either the proposed[13] universal blackbody radiation at 3.5°K[14-17] does not exist, or that there exists a second source of high-energy electrons. This source would have an intensity and spectrum of the form $dJ(E)/dE=0.45\times E^{-1.1}$ (m^2 sec sr GeV)$^{-1}$ below 20 GeV and a power-law spectrum with a negative exponent $\gamma=2.1$ extending from 20 to 350 GeV. Furthermore, this source is assumed to contain an excess of positrons.

In this Letter we wish to point out that 3.5°K blackbody radiation is compatible with the recent data on the electron energy spectrum[2,5,8,9] without invoking a second source of electrons. Furthermore, the spectrum assumed by Daniel and Stephens does not clearly follow from the experimental results. We also wish to point out that their measurements of the east-west asymmetry at energies >12 GeV are open to the alternative interpretation that they partly contain re-entrant albedo electrons.

To illustrate our point, we have plotted in Fig. 1 the results of electron energy-spectrum measurements[2,5,8,9] at the present solar minimum period. These data indicate a change of slope in the electron energy spectrum around 7-10 GeV. Data between 1 and 5 GeV can be represented by the power law

$$\frac{dJ}{dE}=30E^{-\gamma}\text{ electrons/(m}^2\text{ sec sr GeV)},\qquad(1)$$

with an exponent $\gamma=1.8\pm0.15$. If we assume that the halo electron energy spectrum is given by Eq. (1) there is no conflict with the observations of the nonthermal radio background.[18-20] It has been shown many times[21-23] that the important processes for energy loss of the electrons are Compton scattering, synchrotron radiation, and leakage from the halo. With the revised value for the Compton-scattering term resulting from the presence of a universal blackbody radiation (~3.5°K) one obtains

$$-\left(\frac{dE}{dt}\right)_C=7.5\times10^{-26}W_{\rm ph}E^2[\text{eV/sec}]\text{ for }E<10^4\text{ GeV};$$

$$-\left(\frac{dE}{dt}\right)_S=3.8\times10^{-15}\langle B_\perp^{\,2}\rangle E^2[\text{eV/sec}],$$

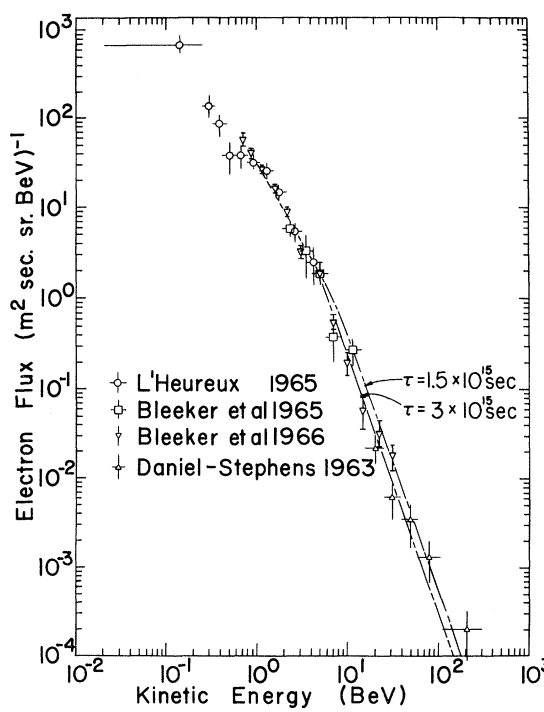

FIG. 1. Calculated equilibrium energy spectrum of electrons in galactic halo with experimental points taken near present solar minimum period. (Refs. 2, 5, 8, 9; the years are the time of the experiment.)

$$\langle B_\perp{}^2\rangle = \tfrac{2}{3}\langle B^2\rangle;$$

$$-\left(\frac{dE}{dt}\right)_\mathrm{L} = \left(\frac{1}{\tau}\right)E[\mathrm{eV/sec}], \qquad (2)$$

where τ is the leakage lifetime of halo electrons and W_ph is the radiation energy density ($\mathrm{eV/cm^3}$) for all photons. Most of the contribution for it comes from the blackbody radiation, $W_\mathrm{ph}(\mathrm{bb}) = 0.71\ \mathrm{eV/cm^3}$.[24] The contribution from starlight, $W_\mathrm{ph}(\mathrm{s.l.})$, in the galactic halo has been estimated by several workers with results varying between[23] 0.063 $\mathrm{eV/cm^3}$ and 0.3 $\mathrm{eV/cm^3}$.[22] Using $W_\mathrm{ph} = 1\mathrm{eV/cm^3}$, $\langle B\rangle = 3\ \mu\mathrm{G}$, and $\tau = 3\times10^{15}$ sec, the rates of energy loss are plotted in Fig. 2 as a function of electron energy. Below 5 GeV the leakage loss (L) is prominent. Compton losses (C) dominate above about 10 GeV. Therefore, in the energy interval 1 to ~5 GeV the slope of the energy spectrum [Eq. (1)] is preserved. However, above ~10 GeV the spectrum will be steepened.[21] Using the method of Daniel and Stephens[2] we obtained for the equilibrium energy spectrum for this energy range

$$\frac{dJ}{dE} = \frac{30E^{-(\gamma+1)}}{(\gamma+1)b\tau}, \qquad (3)$$

where $b = -(1/E^2)[(dE/dt)_\mathrm{S} + (dE/dt)_\mathrm{C}]$. The value of b was evaluated using Eqs. (2). The dashed lines in Fig. 1 are the resulting spectra for two values of τ. Within the uncertainties of the measurements, both values fit the data.

Secondly, Daniel and Stephens'[2] assertion that there exists a positron excess at energies >12 GeV as opposed to the electron excess in the 0.05- to 10-GeV energy interval[10-12] should be interpreted with great caution. Measurements of the E-W asymmetry[1,2,25] are liable to be influenced by re-entrant electrons. Below the geomagnetic cutoff, re-entrant electrons were observed by Verma[26] and Daniel and Stephens.[1] Let N_W and N_E be the number of $e^+ + e^-$ arriving from the west and east directions which are above the cutoff for one charge and below the cutoff for the other. N_W will consist of positive primary and negative re-entrant particles and N_E will have just the opposite, i.e., negative primary and positive re-entrant particles. Then

$$N_\mathrm{W} = P\epsilon_P{}^+ + R(1-\epsilon_R{}^+),$$

$$N_\mathrm{E} = P(1-\epsilon_P{}^+) + R\epsilon_R{}^+, \qquad (4)$$

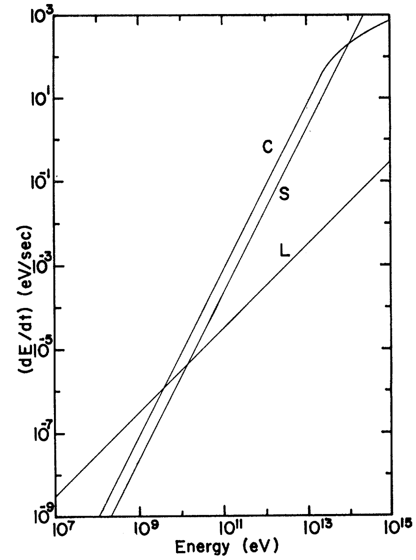

FIG. 2. Electron-energy loss rate in the galaxy by Compton scattering (C), synchrotron emission (5) and leakage out of the halo (L).

where P and R are the sum of e^+ and e^- of primary and re-entrant nature, respectively, from these directions. $\epsilon_P{}^+$ and $\epsilon_R{}^+$ represent the positive fraction $[e^+/(e^+ + e^-)]$ of primary and re-entrant electrons, respectively. The E-W asymmetry is then given by

$$A = 2\frac{P(2\epsilon_P{}^+ - 1) - R(2\epsilon_R{}^+ - 1)}{(P+R)}. \qquad (5)$$

The asymmetry will depend on the relative fluxes of primary and re-entrant electrons. An extrapolation of the measured re-entrant electron spectrum beyond 6 GeV, previously summarized by Verma,[26] leads to a ratio of the re-entrant and primary flux (R/P) of about 20% or more. Daniel and Stephens' data are therefore complicated by the presence of re-entrant electrons. In their paper it is not stated whether a correction for re-entrant electrons was made. Further, in view of the poor statistics the inference of the positive excess among primary electrons having energy between 12 and 25 GeV cannot be considered seriously until confirmed by a direct measurement.

In conclusion we emphasize that in the framework of the galactic-halo model, the measurements of the electron spectrum in the high-energy region are compatible with the presence of a universal blackbody radiation (~3.5°K) if the lifetime of the electrons (τ) is assumed to be ~(1.5-3)$\times10^{15}$ sec.

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GENERALIZATION OF ELECTROMAGNETIC POTENTIALS

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A restricted generalization of the vector potential $\vec{A}$ and the scalar potential φ is demonstrated for cases where $\nabla\cdot\vec{B} \neq 0$.

It is desired here to use a Lagrangian of the form

$$L=\sum_i[-m_ic^2(1-v_i^2/c^2)^{1/2}+(q_i/c)\vec{v}_i\cdot\vec{A}_i-q_i\varphi_i]+(\tfrac{1}{8}\pi)\int d^3x\,[(\dot{\vec{A}}/c+\nabla\varphi)^2-(\nabla\times\vec{A})^2] \tag{1}$$

in classical problems where the magnetic field $\vec{B}$ is not necessarily equal to curl $\vec{A}$.[1] The sum is taken over all particles of the system, while the integral is the electromagnetic field Lagrangian. q_i is a generalized charge or pole-strength parameter for the ith particle and will be defined further.

Equation (1) yields the field equations

$$\Box\vec{A}=-(4\pi/c)\vec{J}+\nabla(\nabla\cdot\vec{A}+\dot{\varphi}/c),\qquad \nabla^2\varphi+\nabla\cdot\dot{\vec{A}}/c=-4\pi\rho, \tag{2}$$

for a generalized charge density $\rho=\sum_i q_i\delta(\vec{r}-\vec{r}_i)$ and a corresponding current density $\vec{J}$