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COSMIC-RAY ELECTRON SPECTRUM AND THE UNIVERSAL BLACKBODY RADIATION AT 3°K

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It is shown that the observed energy spectrum of cosmic-ray electrons between 1 and 350 GeV may be compatible with the existence of a universal blackbody radiation at 3°K, in contrast to the conclusion drawn by Daniel and Stephens in a recent Letter.

Daniel and Stephens[1] have shown that the differential energy spectrum of cosmic-ray electrons between 12 and 350 GeV can be represented as

$$N(E)dE = 12.7E^{-2.1 \pm 0.2}dE \text{ m}^{-2} \text{ sec}^{-1} \text{ sr}^{-1}, \quad (1)$$

where E is the electron energy in GeV. The theoretically calculated spectrum is generally written as[2,3]

$$N(E) = KE^{-\gamma}, \quad (2)$$

where the spectral index γ is determined by the particular mode of acceleration envisaged. Using Fermi's[4] statistical mode of acceleration, and neglecting processes of energy loss, one has $dE/dt = \alpha E$; one deduces that $\gamma = 1 + (\alpha T)^{-1}$ where T is the lifetime of electrons against leakage by diffusion from the acceleration region, and

$$\alpha = u^2 v/c^2 l, \quad (3)$$

where u is the velocity of the magnetic "walls" or "clouds," l is the distance between the walls, and v is the velocity of the particle along the lines of force. With the usual choice for these parameters,[2,3] γ is of the order of 2.4 to 2.5. A value of 2.5 for γ was obtained by Syrovatskii[5] from the assumption that the cosmic rays are produced in nebulae and supernova shells and that the total energy is equally distributed between the kinetic energy of turbulent motion, the magnetic field, and the cosmic rays. This value agrees well with the value of about 0.7 obtained for the spectral index $(\gamma-1)/2$ for the isotropic radio emission.[1]

For higher electron energies, losses due to synchroton radiation and losses due to Compton scattering[6] with starlight photons and 3°K blackbody radiation[7] become important. These losses (particularly the latter[1]) have the effect of increasing the spectral index to a value $\gamma + 1$ at a critical energy E_c, which is proportional[1,2,6] to T^{-1}. Taking T to be 3×10^{15} sec, Daniel and Stephens[1] arrived at a critical energy of about 10-20 GeV; thus for energies >20 GeV the calculated index is 3.4, in strong disagreement with the experimental value of 2.1 ± 0.2. This led Daniel and Stephens to cast doubt on the existence of the 3°K radiation or alternatively to postulate the existence of two separate electron components.

In this paper we will show that the value of T can be 40 times or more smaller. This will invalidate the argument of Daniel and Stephens since it has the effect of increasing E_c from 10 GeV to >400 GeV, a value beyond the range of the experimental data, which extended only to 350 GeV. We note that a value of 2.4 for γ gives very good agreement with the results of Daniel and Stephens, within the limits of experimental error.[8] What factors could contribute to such a large decrease in the value of T? Within a diffusion-model framework,[2,3,9] we have

$$T \sim R^2/lv, \qquad (4)$$

where R, the radius of the acceleration-cum-confinement[10] region, is generally taken to be the radius of the galaxy, assuming a galactic halo. Recently, however, the existence of a halo has been seriously questioned by a number of authors.[11] We thus suggest that the acceleration-cum-confinement region consists of the galactic disk. This idea is supported by the fact that the bulk of the galactic matter (which probably gives rise to the relatively high magnetic field associated with the confinement region) is confined to the galactic disk. Of course, electrons will also be accelerated in discrete sources outside the disk but, in our model, these will not contribute to the local electron flux because of energy losses via synchroton and Compton radiation. This assumption will lead to a considerable decrease in T. The actual value of T will of course depend on the geometry of the appropriate region but we get a rough estimate by comparing the volumes of the disk and halo and noting that $T \propto R^2$. Taking a volume ratio[12] of $\sim 10^{-2}$, a reduction in T by a factor of about 22 is obtained in going from the halo to the disk model. It is clear that a more refined calculation, taking into account the flatness of the disk, will lead to still higher values.[13] Of course, another method that may decrease T is to have a larger mean free path l. It should be emphasized that the value of l is very uncertain[12] and numbers differing by factors of 100 have been quoted by several authors.[2,3,12] It is thus clear that either a decrease in the volume of the accelerating region, an increase in the mean free path, or perhaps a combination of both may lead to an increase in E_C, to a value larger than the highest electron energies measured by Daniel and Stephens.[1]

It might be objected that a decrease in T will cause an increase in the spectral index γ obtained, in the Fermi theory, from the relation $\gamma = (\alpha T)^{-1} + 1$. In fact, a decrease in T resulting from an increase in l will have the effect of also decreasing α [see Eq. (3)] and so lead to a still greater increase in γ. However, there are great difficulties in accepting that the Fermi mechanism in interstellar space is solely responsible as the primary means of accelerating electrons.[5,14] Hence, this disagreement is not to be taken seriously.

We thus suggest that the main cosmic-ray particle acceleration occurs most likely in the envelopes of supernovae via perhaps the radiation acceleration method of Tsytovich,[14] the shock-wave mechanism of Colgate and Johnson,[15] or even the Fermi mechanism itself in the earliest stages of a supernova expansion (where u can become quite large because of violent flows of gas masses in the envelopes). If, in addition, we accept Syrovatskii's model, in which the cosmic rays which leak from the supernova envelope (to be distinguished from the subsequent leakage, with an average time T, from the galactic disk) have a spectrum which is independent of the character of the acceleration inside the envelope, we obtain a γ of 2.5. As we have seen, this value gives good agreement with experiment.

To summarize, we have interpreted the cosmic-ray electron spectrum, not in the role of casting doubt on the existence of a universal 3°K blackbody radiation, but rather as giving evidence that this distribution itself is restricted to the confines of the galactic disk.

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[10]As the subsequent discussion will make clear, the primary acceleration region may be smaller than the confinement region. By the latter we mean a region of high magnetic field—relative to the surrounding area—from which, if the particles escape, their probability of return is practically zero.

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FURTHER EVIDENCE FOR THE H MESON*

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Further evidence for the H meson is presented. The decay angular distributions are found to be consistent with $J^P = 1^+$.

We report here evidence for an enhancement near 1.0 BeV/c^2 in the $\pi^+\pi^-\pi^0$ mass spectrum from the reaction $\pi^+ + d \to \pi^+ + \pi^- + \pi^0 + p + (p)$ at 3.65 BeV/c. The data are taken from the same 3000 events from which other results have been previously reported.[1] Our results are in agreement with the properties of the "H meson" that was observed[2] in the reaction $\pi^+ + p \to \pi^+ + \pi^- + \pi^0 + N^{*++}$ at 4.0 BeV/c.

Mass spectrum.—Figure 1 shows the $\pi^+\pi^-\pi^0$ mass spectra for this experiment and separately for that of Ref. 2. In both sets of data it is required that at least one of the di-pion masses be in the rho region (650-850 MeV/c^2 for our data, 640-860 for the others). A further requirement in the ABBBHLM data is that one of the π^+p combinations is in the $N^*(1238)$ region. The curve illustrated, which applies only to our data, was calculated by multiplying that fraction of an isotropic Dalitz plot that contains at least one rho by a three-pion phase space. We have made a similar calculation using a Dalitz-plot density appropriate for an $I = 0$, $J^P = 1^+$ three-pion state decaying into $\rho + \pi$ via s wave. This increases the 1-BeV/c^2 shoulder somewhat but still falls far short of explaining the bump in the data.

Using a background of this type we have fitted the data in 20-MeV/c^2 bins to a Breit-Wigner resonance form and find a central value $M = 998 \pm 10$ MeV/c^2 with a width at half maximum of 75 ± 30 MeV/c^2. This is to be compared with Ref. 2 which gives $M = 975 \pm 15$ MeV/c^2 and $\Gamma = 120$ MeV/c^2. Subtracting our resolution of 30 MeV/c^2 from our measured width gives 45 ± 30 MeV/c^2 for the width of the H meson. This procedure gives reasonable widths for both the ω^0 and A_2^0.[1]