Calculations of the <1 GeV Galactic Electron Spectrum Using a Monte Carlo Diffusion Program and a Comparison with the Low Energy Galactic γ-Ray Spectrum

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Abstract

We have used a Monte Carlo diffusion model to calculate the interstellar electron spectrum from a few MeV to 1 GeV and above. The parameters governing the diffusion, the boundary distance (halo size) and the matter density are determined from the application of this same program to the propagation of cosmic ray protons and nuclei including radioactive ones. The calculated interstellar electron spectrum is found to flatten from an exponent ~ that of the source spectrum at 1 GeV to an exponent ~1.6 between 20 and 80 MeV because of ionization energy loss. The intensity of electrons of a few MeV is thus less than a simple extrapolation of the spectral index at 1 GeV would imply. In the energy range from a few MeV to ~100 MeV this calculated electron spectrum is very similar to that required to produce the galactic γ-rays observed by COMPTEL and EGRET. This suggests that electron brehmstrahlung is the dominant contributor to the measured γ-ray spectrum in this energy range and that the interstellar electron source spectrum has a spectral index = -2.40±0.05.

1. Introduction

The electron spectrum below ~ 1 GeV in the Galaxy may be deduced from measurements of the galactic radio spectrum below ~ 50 MHz and by measurements of the γ-ray spectrum below ~ 100 MeV. The radio emission is due to synchrotron emission from <1 GeV electrons; the γ-ray emission is primarily due to the bremsstrahlung emission from electrons of ~ twice the γ-ray energy. These two types of emission depend on the B field and the matter density respectively, both of prime importance to define the propagated spectrum of the electrons themselves. To fully incorporate these parameters into a propagation model for electrons, we have used a Monte Carlo diffusion model in which the B field is defined by the high energy electron spectrum and the matter density defined by the propagation of cosmic ray nuclei including radioactive ones. The resulting calculated low energy electron spectrum is presented and compared with that deduced from the radio spectrum observed near the galactic poles. This spectrum is then used to determine the expected γ-ray spectrum.

2. Calculation of the Electron Spectrum and the Resulting γ-Ray and Radio Spectra

The Monte Carlo diffusion model is described more fully in Webber and Rockstroh, 1997. For the calculations here we use a value of B_0=5μG and a characteristic z scale height of B=1.5 kpc, a value of the matter density n_0=1.2cm^{-3} and a characteristic matter scale height of 0.2 kpc, giving a total line integral of matter density perpendicular to the galactic disk of 8.4x10^{20} cm^{-2}, consistent with measured values. The calculated interstellar (IS) electron spectra for electron source spectral indices of –2.2, -2.3 and -2.4 are shown in Figure 1. These spectra are observed to flatten from an exponent equal to that of the source spectrum at ~1 GeV to an average exponent ~1.6 between 10-100 MeV because of ionization energy loss. The intensity of IS electrons of a few MeV is thus less than a simple power law extrapolation of the spectral index at 1 GeV would imply.

The IS electron spectrum implied by the polar radio spectrum (Peterson, et al., 1999) is shown above ~0.1 GeV in Figure 1. At lower energies we use the calculations of the bremsstrahlung emission spectrum from electrons made by Skibo, 1993. These calculations are shown in Figure 2 again for electron source spectra of –2.2, -2.3 and -2.4. It should be noted that the bremsstrahlung spectrum from a spectrum of electrons whose index is changing with energy, as in this case, has a very similar shape to the electron spectrum itself, but scaled down in energy by a factor ~0.4. Thus the jxE^2 bremsstrahlung spectra from the electron spectra shown in Figure 1 have their peaks at ~100-200 MeV as indicated in Figure 2. If these spectra are superimposed on the galactic center γ-ray spectrum between 1-100 MeV from COMPTEL and EGRET presented by Strong et al., 1997, as shown in Figure 3, it is seen that an electron source index =-2.4 is favored for those electrons responsible for the bremsstrahlung emission. This source spectral index also provides a good fit to the electron spectrum deduced from the polar radio spectrum and from the directly measured high energy electron data (Rockstroh, et al., 1999).

3. Summary and Conclusions

We find that an electron spectrum with a source spectral index = -2.4±0.05, propagated using a Monte Carlo diffusion model with the propagation parameters determined by high energy electron and cosmic ray nuclei measurements, can explain both the low frequency galactic radio spectrum measurements and the COMPTEL and EGRET γ-ray measurements toward the galactic center below ~100-200 MeV. Source spectra very different from –2.4, e.g. –2.2 or less, will not fit the low energy γ-ray measurements or provide a satisfactory fit to the directly measured electron spectra above a few GeV. This implies that the shape of the low energy electron spectrum towards the galactic center is not greatly modified by the possibly different propagation conditions whereas the high energy proton spectrum may be significantly modified (Webber, 1999) thus leading to a different γ-ray spectrum above 1 GeV arising from Π° production from these high energy protons. As a result of this a different cosmic ray p/e ratio (at 1 GeV) may apply nearer to the galactic center as compared with the local IS ratio of 20±5 deduced from measurements at the Earth.

References

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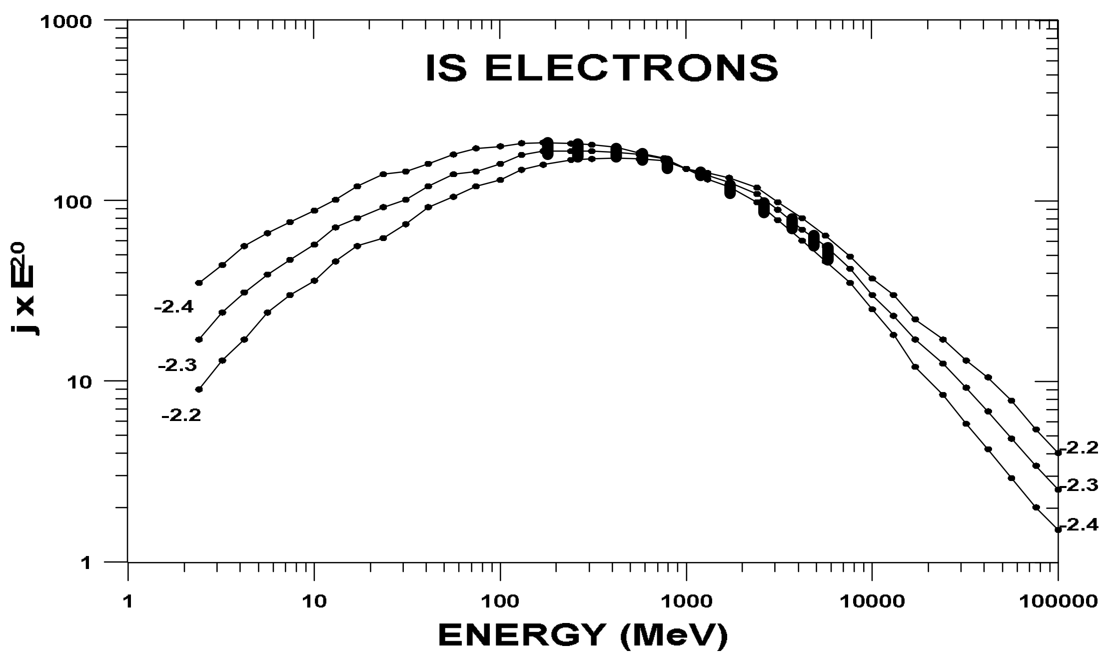

Figure 1: Interstellar electron spectra calculated using a Monte Carlo diffusion model, for source spectra with exponents = -2.2, -2.3 and –2.4, all normalized to an intensity = $1.5x10^2/m^2 \cdot s \cdot sr \cdot GeV$ at 1 GeV. Estimated IS electron spectrum from 0.1-6 GeV as derived from studies of the polar radio spectrum by Peterson et al., 1999, is also shown.

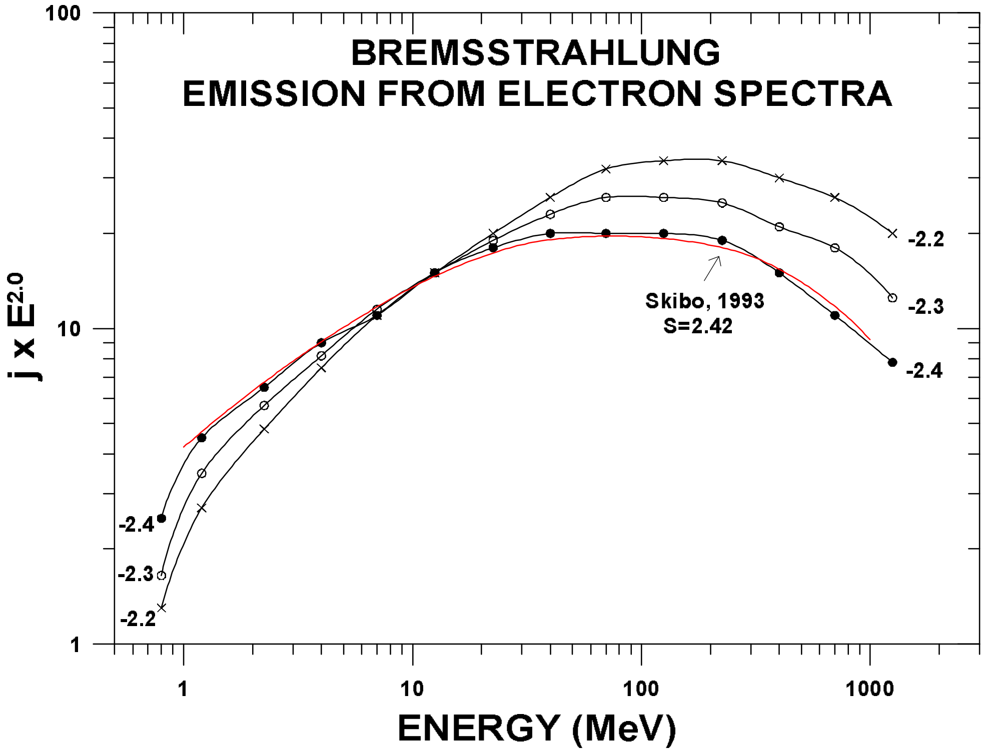

Figure 2: Bremsstrahlung spectra from electron spectra presented in Figure 1. Spectrum obtained by Skibo, 1993, for a very similar electron source spectrum = -2.42 is also shown as a red line.

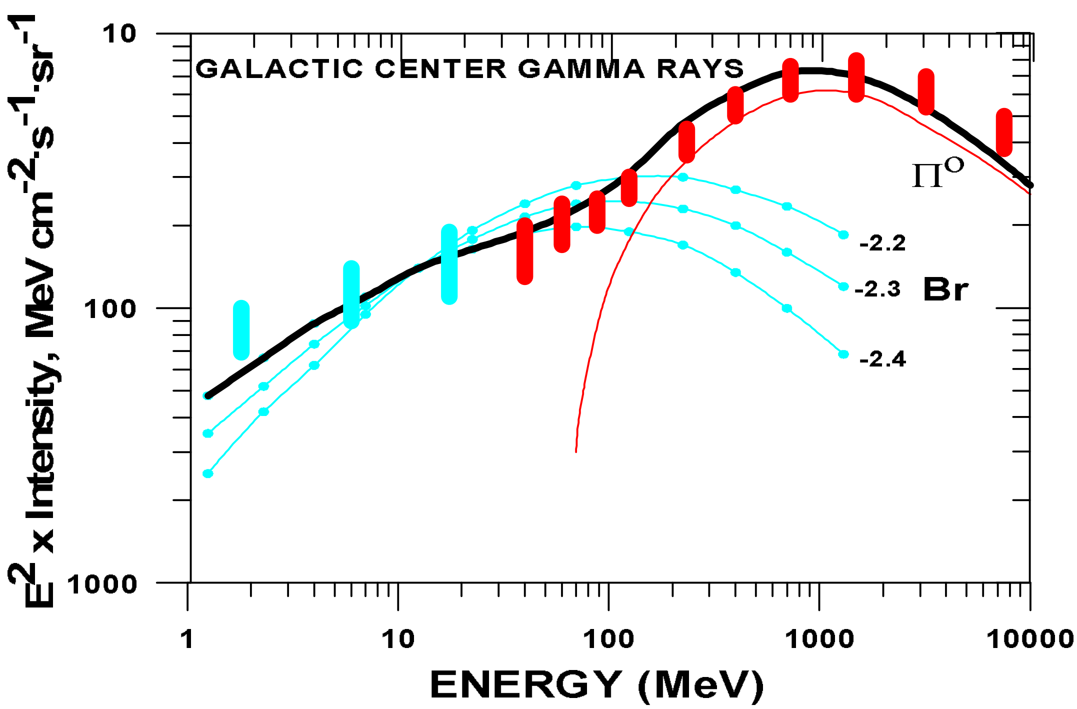

Figure 3: Galactic center γ-ray spectrum from COMPTEL & EGRET for -5°< b<+5° from Strong, et al., 1997. Predictions are: Blue curves-bremsstrahlung spectra from electron source spectra with indices = -2.2, -2.3, -2.4 from this paper. Red curve-Π° spectra from proton spectrum derived in Webber, 1999. Solid curve-combined Π° spectrum and –2.40 bremsstrahlung spectrum.