SNR and fluctuations in the diffuse Galactic continuum emission

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Introduction

We have previously described a numerical model for the Galaxy encompassing primary and secondary cosmic rays, γ-rays and synchrotron radiation in a common framework. Up to our code 'galprop' handled 2 spatial dimensions (*R,z*) together with particle momentum *p*. This was used as the basis for studies of cosmic-ray (CR) reacceleration, the size of the halo, positrons, antiprotons, dark matter and the interpretation of diffuse continuum γ-rays. Some aspects cannot be addressed in such a model: for example the stochastic nature of the cosmic-ray sources in space and time, which is important for high-energy electrons with short cooling times, and local inhomogeneities in the gas density which can affect radioactive secondary/primary ratios. The motivation for studying the high-energy electrons is the observation of the >1 GeV excess in the EGRET spectrum of the Galactic cmission, which has been proposed to originate in inverse-Compton emission from a hard electron spectrum; this hypothesis can only be reconciled with the local directly-observed steep electron spectrum if there are large spatial variations which make the local region unrepresentative of the large-scale average spectrum.

Strong et al. (2000) presented a study of diffuse γ-rays based on the 2D model.

First results from an extension of the model to 3D, which can cover these issues, are presented here.

Model

The galprop code, which solves the cosmic-ray propagation equations on a grid, has been entirely rewritten (in C++) using the experience gained from the original version and including both 2D and 3D options. Cosmic-ray nuclear reaction networks are included with a comprehensive new cross-section database. This allows the models to be tuned on stable and radioactive CR primary/secondary ratios, in particular B/C and ^{10}Be/^{9}Be. The 2D mode essentially duplicates the original version. In 3D (x,y,z,p) the propagation is solved as before using a Crank-Nicolson scheme. The additional dimension increases the computer resources considerably but a 200 pc grid cell is still practicable. The main enhancement is the inclusion of stochastic SNR events as sources of cosmic rays. The SNR are characterized by the mean time t_{SNR} between events in a 1 kpc^3 unit volume, and the time t_{CR} during which an SNR actively produces CR ; the normalization is provided by the observed CR fluxes. The propagation is first carried out for a smooth distribution of sources to obtain the long timescale solution; then the stochastic sources are started and propagation followed on a fine time scale for the last 10^7 years or so. For high-energy electrons (TeV) which lose energy on timescales of 10^5 years the effect is a very inhomogeneous distribution. The amplitude of the fluctuations depends on the two parameters t_{SNR} and t_{CR} which are both poorly known . t_{SNR} is adjusted to be consistent with the observed present number of SNR in the Galaxy and estimates of the SNR rate; models for shock acceleration in SNR indicate $10^4 < t_{CR} < 10^5$ yr, the sources switching off at the adiabatic/radiative transition.

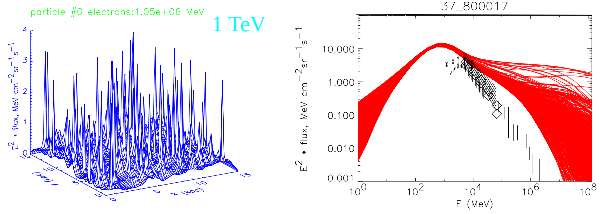
For $t_{SNR} = 10^4$ years ("standard" Galactic SN rate 3/century) the TeV electron distribution is inhomogeneous, but still none of the spectra resemble even remotely that observed locally.

For $t_{SNR} = 10^5$ years and $t_{CR} = 10^4$ years (Galactic SN rate 0.3/century) the distribution above 100 GeV is even more inhomogeneous and the spectrum fluctuates greatly. Some of the spectra resemble that observed locally within a factor of a few.

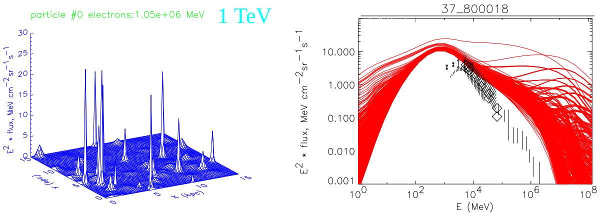
1 TeV electron distributions at z=0

Electron spectra fluctuations over the Galaxy

$t_{SNR} = 10^4$ yr, $t_{CR} = 10^4$ yr



$t_{SNR} = 10^5$ yr, $t_{CR} = 10^4$ yr



Conclusion.

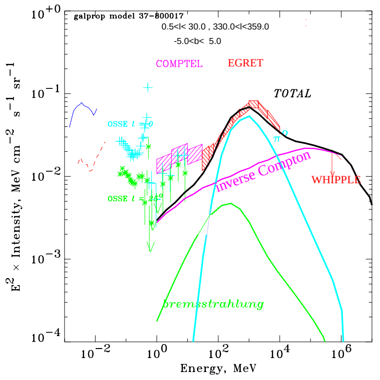
We conclude that the 'hard electron spectrum' hypothesis for the EGRET γ-ray excess requires a lower than standard SN rate, with correspondingly large power requirements for acceleration of electrons per SNR. It is possible that the rate of *CR-producing* SNR could be lower than that of all SNR, so that a sufficiently low rate may indeed be possible, but this seems somewhat unlikely in view of the power requirements.

This is different from the conclusion of Pohl & Esposito (1998) , who stated that a hard electron spectrum model is consistent with observations considering the fluctuations, but who included however a dispersion in the electron injection spectral index which increases the variations further.

Galactic diffuse TeV γ-rays

Recently observation of the Galactic plane (l ~ 40°) have been reported by the Whipple Observatory (LeBohec et al. 2000), which place limits on the >500 GeV intensity. We have extended our predicted spectrum for a hard electron injection spectrum (injection $E^{-1.8:}$ introduced to fit the EGRET data) to the TeV range. Since the maximum energy of accelerated electrons is unknown we consider the case 100 TeV. The SNR shock-acceleration models of Baring et al. (1999) suggest a cutoff around 1 TeV which imply a cutoff in the γ-rays around 10 GeV in which case the predicted intensities are well below the Whipple limit and a detection is not to be expected.

$E_{e,max} = 100$ TeV



Spectrum of Galaxy l=330-30°, |b|<5°

Model: hard electron injection spectrum with reacceleration

EGRET data from Strong & Mattox 1996, COMPTEL from Strong et al. 1999

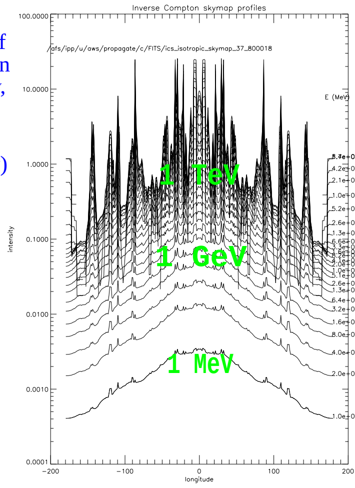
WHIPPLE: LeBohec et al. (2000)

Even for $E_{e,max}$=100 TeV the predicted spectrum is from inverse-Compton emission is compatible with the Whipple upper limit, and lower $E_{e,max}$ will be also consistent with Whipple, but it is clear that an improved limit would quickly provide a critical test for this model.

Effect on the gamma-ray sky

The inverse-Compton emission becomes increasingly clumpy at high energiesdue to the effect of SNR. The effect is already visible at a 1 GeV and will be an important signature at GLAST energies up to 100 GeV.

Longitude profiles of
inverse-Compton emission
as a function of energy,
showing the increasing
fluctuations at high energy
due to SNR (rate 3/century)



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