Diffuse gamma-ray emission: Galactic and extragalactic

Martin Pohl

DSRI, Juliane Maries Vej 30, 2100 Copenhagen Ø, Denmark

Abstract
Here is reviewed our current understanding of Galactic and extragalactic diffuse γ-ray emission. The spectrum of the extragalactic γ-ray background above 30 MeV can be well described by a power law with photon index $\alpha = 2.1$. In the 2-10 MeV range a preliminary analysis of COMPTEL data indicates a lower intensity than previously found, with no evidence for an MeV bump. Most of the models of a truly diffuse background seem to be in conflict with the observed spectrum. Though AGN are the most likely input from discrete sources, two independent attempts to model the high energy background as the superposition of unresolved AGN indicate that AGN underproduce the observed intensity. Therefore the origin of the extragalactic γ-ray background is still unknown.

The Galactic diffuse γ-ray continuum is more intense than expected both at very low energies ($\leq 100$ keV) and at high energies ($\geq 1$ GeV). The published models for these excesses all involve cosmic ray electron interactions. While the low energy excess may have something to do with in-situ acceleration of electrons, the excess at high energies may be understood if the sources of cosmic ray electrons are discrete. The measured energy spectrum of the diffuse Galactic γ-ray continuum radiation thus may provide new insights into the acceleration of cosmic rays.

The extragalactic gamma-ray background
The extragalactic diffuse emission at γ-ray energies has interesting cosmological implications since the bulk of these photons suffer little or no attenuation during their propagation from the site of origin. Before the launch of the Compton Gamma-Ray Observatory (CGRO), several balloon experiments (White et al. 1977; Schönfelder et al. 1980) and the γ-ray spectrometer flown aboard three Apollo flights (Trombka et al. 1977) showed the presence of a feature in the few MeV range, that was in excess of the extrapolated hard X-ray continuum. At higher energies, above 35 MeV, the SAS-2 satellite provided the first clear evidence for the existence of an extragalactic γ-ray component (Fichtel et al. 1975).

The first all-sky survey in low energy γ-rays (1 MeV – 30 MeV) has been performed by COMPTEL and at higher energies, above 30 MeV, by EGRET on board CGRO. The improved sensitivity, low instrumental background and a large field of view of these instruments have resulted in significantly improved measurements of the extragalactic γ-ray background. In the following I shall briefly summarize the recent
analysis results, and then I shall discuss the implications of these new findings on the origin of the extragalactic diffuse emission and current models thereof.

**COMPTEL results (1-30 MeV)**
In the 1-10 MeV band diffuse studies tend to be complicated by difficulties in fully accounting for the instrumental background, which is in general composed of ‘prompt’ and ‘long-lived’ components. The prompt background is instantaneously produced by interactions of energetic particles in the spacecraft and thus it modulates with the instantaneous local cosmic-ray flux which is monitored by the veto dome. A linear extrapolation to zero veto count rate is used to eliminate the prompt background contribution. The long-lived background is caused by de-excitations of activated radioactive isotopes with long half lives, for which the decay rate is not directly related to the instantaneous cosmic ray flux. The long-lived background events are identified by their characteristic decay lines in the detector spectra. Monte-Carlo simulations of the isotope decay are then used to determine the absolute contribution of each of the isotopes.

![Multiwavelength spectrum of the diffuse extragalactic emission from X-rays to γ-rays](image)

Fig.1. Multiwavelength spectrum of the diffuse extragalactic emission from X-rays to γ-rays taken from Sreekumar et al. (1997). The estimated contributions from Seyfert I (dot-dashed) and Seyfert II (dashed) are from the model by Zdziarski (1996); steep-spectrum quasar contribution (triple dot-dashed) is taken from Chen, Fabian and Gendreau (1997); Type Ia supernovae (dotted) is from The et al. (1993). Also included is a possible blazar contribution (long dashed) assuming an average power law index of -1.7 below 4 MeV (McNaron-Brown et al. 1995) and -2.15 at higher energies (Mukherjee et al. 1997). The thick solid line indicates the sum of all components.
The diffuse flux measured by COMPTEL still includes contributions from the Galactic diffuse emission and γ-ray point sources in the field of view. The results below 9 MeV should, anyway, be considered preliminary. Nevertheless it is clear to date that the 2-9 MeV flux is significantly lower than measured in the pre-COMPTEL era. There is no evidence for an MeV-bump (Kappadath et al. 1996), a result supported also by a recent analysis of SMM data (Watanabe et al. 1997). The 9-30 MeV flux is compatible with earlier measurements and also with the extrapolation of the EGRET spectrum. The measured 9-30 MeV spectra from the Virgo and South Galactic Pole regions are consistent with each other and hence with an isotropic nature for the diffuse radiation (Kappadath et al. 1997). The new results are shown in Figure 1 compared with the earlier measurements.

EGRET results (30 MeV to 100 GeV)
At γ-ray energies above 10 MeV the analysis of diffuse emission is complicated by difficulties in accurately accounting for the Galactic diffuse emission. The following approach is adopted for the EGRET data. The observed intensity $I_o$ is assumed to be made up of a Galactic, $I_g$, and an extragalactic component, $I_{eg}$. The extragalactic intensity is then derived by a straight line fit to a plot of observed emission versus model prediction of Galactic emission (Sreekumar et al. 1998). The spectrum is determined to be consistent with a single power law of index (2.1 ± 0.03). The intensity above 100 MeV is $(1.45 \pm 0.05) \cdot 10^{-5} \text{cm}^{-2} \text{sec}^{-1} \text{sr}^{-1}$, which may include some unaccounted extended Galactic diffuse emission. The spectrum derived by Sreekumar et al. (1998) is also shown in Figure 1.
Earlier, independent analysis yielded a power law index (2.11 ± 0.05) (Osborne, Wolfendale and Zhang 1994), or an index (2.15 ± 0.06) and an integrated intensity above 100 MeV of $(1.24 \pm 0.06) \cdot 10^{-5} \text{cm}^{-2} \text{sec}^{-1} \text{sr}^{-1}$ (Chen, Dwyer and Kaaret 1996), which are perfectly consistent with Sreekumar’s result in the power law index, but indicate systematic uncertainties in the derivation of the absolute intensity level.

Models of the extragalactic γ-ray background
A large number of possible origins for the extragalactic diffuse γ-ray emission have been proposed over the years. Theories of diffuse origin include scenarios of baryonic symmetric universes (Stecker, Morgan, and Bredekamp 1971), primordial black hole evaporation (Page and Hawking 1976), massive black holes that collapsed at redshifts of $z \sim 100$ (Gnedin and Ostriker 1992), and annihilation of exotic particles (Silk and Srednicki 1984, Rudaz and Stecker 1991). All of the theories predict continuum and line contributions that are not observed to date.
Models based on discrete source contributions have considered a variety of source classes. The γ-ray intensity expected from normal galaxies has been estimated to be 5-10% of what is observed (e.g. Lichti, Bignami, and Paul 1978). Cosmic ray interactions with intergalactic gas in groups and clusters of galaxies may add to this (Dar and Shaviv 1995). However, the energy spectra of the Galactic and intergalactic diffuse γ-rays are significantly different from those measured by EGRET for the extragalactic diffuse radiation, hence these proposed sources are unlikely to
provide much more than 10% of the observed extragalactic intensity. It has been postulated for over 2 decades that unresolved active galactic nuclei (AGN) might be the source of the extragalactic diffuse emission (Bignami et al. 1979). Now the EGRET data prove that a sub-class of AGN, namely blazars, are strong γ-ray emitters (Mukherjee et al. 1997). A comparison of the spectra of γ-ray blazars with the diffuse spectrum gives ambiguous results. Averaging the best-fit indices of power law fits to the individual γ-ray spectra blazars yields (2.15 ± 0.04), in good agreement with the index of the diffuse spectrum (Mukherjee et al. 1997). Co-adding the individual intensity spectra of blazars on the other hand results in an ‘average’ spectrum which is distinctively softer than the extragalactic background and not well represented by a power law (Pohl et al. 1997a).

For any estimate of the intensity of diffuse emission from unresolved blazars, knowledge of the luminosity distribution and the evolution function is needed. Chiang and Mukherjee (1998) have used the EGRET γ-ray blazar data alone to calculate the evolution and luminosity function of γ-ray loud AGN. These authors report evidence for a low-luminosity cutoff in the γ-ray AGN luminosity function. With this part of the luminosity function better constrained, they estimate that γ-ray loud AGN contribute an intensity of

\[ I_{AGN} = (3 \pm 1) \times 10^{-6} \text{ cm}^{-2}\text{sec}^{-1}\text{sr}^{-1} \]

to the diffuse background, which is about 25% of the background observed by EGRET. Several authors have estimated the contribution from blazars by assuming an intimate relationship between γ-ray and radio emission from blazars. Beyond applying the radio evolution function to the γ-ray emitting blazars, the γ-ray fluxes have been compared with catalogued radio fluxes to derive a luminosity correlation which can be integrated to obtain the blazar contribution to the diffuse background (Padovani et al. 1993; Stecker, Salomon and Malkan 1993; Setti and Woltjer 1994; Erlykin and Wolfendale 1995). In most cases, the calculations are within 50% of the observed intensity. A word of caution about these estimates seems appropriate: there is certainly some sort of loose relation between radio and γ-ray emission of blazars visible, for example, in that EGRET preferentially sees radio bright objects (Mattox et al. 1997), but careful analysis shows that there is no direct correlation with dispersion of less than a factor 2 (Mücke et al. 1997).

Recently, Mücke and Pohl (1997, 1998) have presented a calculation in which they assumed that radio loud and γ-ray loud blazars are the same sources in principle. They would share properties like evolution, geometry, and energy input into the jet, but the actual radiation processes responsible for radio and γ-ray emission would be different. Using a specific inverse-Compton scattering model for the γ-ray production, these authors deduce that AGN could provide only about 40% of the observed diffuse background. However, they also state possible systematic problems in their study in properly accounting for the contribution of BL Lacs. All these studies either assume evolution similar to that observed in radio source studies, or attempt to deduce the evolution directly from the few high-z sources observed with EGRET. All of them need to introduce a redshift cutoff at which to stop integration of the blazar luminosity function. The choice of redshift cutoff has considerable influence on the estimate of the diffuse radiation from blazars.
Gamma-rays of energy $\geq 10$ GeV emitted at redshifts of $z \geq 4$ should be reprocessed in a pair creation/annihilation cascade before reaching the earth. One may therefore argue that the power law shape up to 100 GeV exhibited by the observed diffuse background is incompatible with a significant fraction of it originating from $z \geq 4$ objects. Nevertheless, the systematic uncertainty imposed by the redshift cutoffs is considerable. It is disturbing though, that two independent studies indicate that AGN underproduce the diffuse background. If nothing else, it tells us that to date we do not understand the origin of the diffuse extragalactic $\gamma$-ray radiation.

The Galactic diffuse gamma-ray emission

Prior to the launch of CGRO, a number of observations of the Galactic diffuse emission were made with instruments covering generally non-overlapping energy ranges. At MeV energies the $\gamma$-ray spectrometer on SMM (Harris et al. 1990) has provided high resolution spectra of the Galactic emission with little spatial information. At higher energies above 50 MeV SAS-2 and COS-B have observed the Galactic plane with better spatial resolution, but moderate energy resolution (for a review see Bloemen 1989). The intermediate energy range remained uncharted. More recently the instruments OSSE, COMPTEL, and EGRET on CGRO have provided us with a wealth of data of the Galactic diffuse $\gamma$-ray emission, and thus with a much clearer understanding of the spectrum and the spatial distribution of the line and continuum radiation. In the next sections I will examine the main results of these observations, particularly those which fail to conform with the standard picture. Finally I shall discuss the constraints for cosmic ray physics thus derived.

$\gamma$-ray line emission

Galactic $e^+/e^-$ annihilation line radiation

Since observations in the late 1970s gave the first evidence of the 511 keV positron annihilation line (Leventhal, MacCallum and Stang 1978), the Galactic center region has been observed by numerous experiments. These observations have not been able to determine the distribution of line emission due to limited spatial resolution (Tueller 1993, Skibo, Ramaty and Leventhal 1992). The situation has also been complicated by apparently time-variable emission (Riegler et al. 1981, Leventhal et al. 1982), which was thought to be caused by positrons escaping from compact sources (Ramaty et al. 1992).

Recently, the data taken with OSSE have been combined with scanning observations by TGRS and SMM to produce maps of the narrow Galactic 511 keV line emission (Purcell et al. 1997). The resulting maps and modelling of the combined data give evidence for three distinct spatial features: the Galactic plane, a central bulge, and an extended emission region at positive latitudes above the Galactic center. Purcell et al. find this asymmetric distribution to be in good agreement with nearly all historic observations, without invoking time variability. Considering
fluxes rather than the spatial distribution, supernovae seem capable of producing positrons at the rate required to account for the observed 511 keV emission (Purcell et al. 1997).

The positive latitude feature is suggestive of an outflow from the Galactic center. The extended nature of the emission together with the lack of a high-density target seem to argue against jet activity from one or more of the black-hole candidates residing near the Galactic center. As an alternative it has been proposed that the high-latitude feature is associated with a fountain of radioactive debris produced by enhanced supernova activity in the Galactic center region (Dermer and Skibo 1997).

Galactic nuclear de-excitation $\gamma$-ray line emission

Nuclear de-excitation $\gamma$-ray lines provide a unique tracer for low energy ($\sim 2 - 100$ MeV/nuc) cosmic ray nucleons. These are well known from solar flares (Share, Murphy, and Ryan 1997), but no compelling evidence was seen from other sources prior to CGRO, although some claims were made.

An extensive evaluation of candidate $\gamma$-ray lines from nuclear interactions was presented by Ramaty, Kozlovsky and Lingenfelter (1979). The main candidate lines are from $^{12}\text{C}$ at 4.4 MeV and $^{16}\text{O}$ at 6.1 MeV. The lines from energetic nuclei are broader than those of ambient nuclei, hence both can be distinguished. Gamma-ray spectroscopy of nuclear de-excitation lines thus provides a potentially powerful tool to study low energy cosmic ray nuclei and their relative acceleration. It was not predicted, however, that CGRO would be able to detect such lines.

Preliminary results of COMPTEL observations of the inner Galaxy show some, but not convincing evidence for line structure in the spectrum, completely in line with theoretical expectations (Bloemen and Bykov 1997). It came as a surprise when early COMPTEL observations of the Orion region revealed intense emission in the 3-7 MeV band which was soon attributed to Carbon and Oxygen de-excitation lines (Bloemen et al. 1994). Later COMPTEL observations seemed to confirm the detection, though a slightly different spatial distribution of the emission was obtained (Bloemen et al. 1997). OSSE has so far not detected this emission in Orion (Murphy et al. 1996), which can be reconciled with the COMPTEL results only if the source of emission is very extended.

The existing observational limits on diffuse X-ray emission from inverse bremsstrahlung, $\gamma$-ray continuum emission following $\pi^0$-decay, and $\gamma$-ray line emission of heavier nuclei in the 1-3 MeV band, require substantial fine tuning in attempts to model the Orion source as Carbon and Oxygen de-excitation emission (Ramaty, Kozlovsky, and Tatischeff 1997, and references therein). However, alternative models have not been able to explain both the observed spectrum and the apparent lack of time variability (see Bloemen and Bykov 1997).

Recently it has been found by the COMPTEL team that background subtraction techniques used so far may be insufficient. A re-analysis of the COMPTEL Orion data is on the way and it is unclear to what extent the results will change.
Galactic $\gamma$-ray continuum emission

Confusion and point sources
The analysis of the galactic diffuse emission can be seriously complicated by unresolved galactic point sources which may have a sky distribution similar to that of interstellar gas. Because of six objects already detected, pulsars are the most likely input from discrete sources. Many authors have addressed this problem on the basis of pulsar emission models (e.g. Yadigaroglu and Romani 1995; Sturner and Dermer 1996) and consistently estimated the contribution of pulsars to the diffuse $\gamma$-ray intensity, above 100 MeV integrated over the whole sky, to be a few percent. Another strategy is to base the analysis only on the observed properties of the six identified $\gamma$-ray pulsars, which also allows an inspection of the spectrum of the unresolved pulsars (Pohl et al. 1997). It is found that pulsars contribute mostly at $\gamma$-ray energies above 1 GeV, and preferentially exactly in the Galactic plane where they can provide more than 20% of the observed emission for a reasonable number of directly observable objects.

Estimates for the contribution of discrete sources other than pulsars are very uncertain due to the lack of clear identification of $\gamma$-ray sources with any known population of Galactic objects. It is interesting to see that roughly ten unidentified EGRET sources can be associated with supernova remnants (SNR) or with OB associations, or with both (SNOBs) (e.g. Sturner and Dermer 1995; Esposito et al. 1996; Yadigaroglu and Romani 1997). Obviously these sources may also be radio-quiet pulsars or highly dispersed radio pulsars.

The spatial distribution of $\gamma$-ray emission
Observations of the Magellanic Clouds with EGRET have finally settled a long-standing debate on whether cosmic rays in the GeV energy range are Galactic or extragalactic. The $\gamma$-ray flux of the Large Magellanic Cloud is weakly less (Sreekumar et al. 1992), and that of the Small Magellanic Cloud is strongly less (Sreekumar et al. 1993) than expected, if cosmic ray protons were uniformly distributed in space. Therefore the bulk of the locally observed protons at GeV energies must be Galactic, and we have to think about which Galactic accelerators are capable of producing cosmic rays with a source power of $\sim 10^{41}$ erg/sec.

The spatial distribution of diffuse Galactic $\gamma$-rays is usually described as ‘the gradient’, that is a plot of the decline of $\gamma$-ray emissivity per H-atom in the Galactic plane versus the galactocentric radius. This approach implicitly assumes that gas interactions (i.e. $\pi^0$ production and bremsstrahlung) dominate over inverse Compton scattering in the Galactic disk. To investigate the $\gamma$-ray emission originating from $\pi^0$-decay and bremsstrahlung, we need some prior knowledge of the distribution of interstellar gas in the Galaxy. This includes not only HI but also H$_2$, which is indirectly traced by CO emission lines, and HII, which is traced by H$\alpha$ and pulsar dispersion measurements. Even in case of the directly observable atomic hydrogen we obtain only line-of-sight integrals, albeit with some kinematic information. Any deconvolution of the velocity shifts into distance is hampered
by the line broadening of the contribution from individual gas clouds and by the proper motion of clouds with respect to the main rotation flow.

Different authors use different models of the 3D gas distribution in the Galaxy and thus calculate different gradients (e.g. Strong and Mattox 1996; Erlykin et al. 1996a). Detailed analysis of isolated gas clouds in the solar vicinity shows that both the $\gamma$-ray emissivity and the CO line flux to molecular gas mass conversion factor, $X$, can vary from place to place in the Galaxy (Digel et al. 1995; Digel et al. 1996; Erlykin et al. 1996b). Any comparison of gradients with the Galactic distribution of putative cosmic ray sources should therefore be made with care. It may be safe to say, however, that the cosmic ray intensity decreases somewhat from the inner Galaxy to the outer Galaxy.

The Galactic diffuse $\gamma$-ray spectrum at low energies

The OSSE (Purcell et al. 1996) and COMPTEL (Strong et al. 1994, 1996) instruments have provided evidence that the diffuse Galactic continuum emission extends down to photon energies below 100 keV, as shown in Figure 2. In an analysis of Galactic plane observations made with OSSE (Purcell et al. 1996), it was found that when the contribution from prominent point sources monitored during simultaneous observations with SIGMA is subtracted from the Galactic center spectrum measured with OSSE, the residual intensity is roughly constant over the central radian of the Galaxy, but is lower by a factor 4 at $l \approx 95^\circ$ (Skibo et al. 1997). Estimates based on the luminosities and number-flux distributions of Galactic sources indicate that the point source contribution to the hard X-ray emission from the Galactic plane is less than 20% (Yamasaki et al. 1997; Kaneda 1997). The residual source-subtracted spectrum of this emission changes from a photon index $\alpha = 1.7$ at energies above 200 keV (Strong et al. 1994), to a photon index $\alpha = 2.7$ at lower energies (Purcell et al. 1996). Thus the soft $\gamma$-ray continuum from the Galactic plane is more intense than the extrapolation of the higher energy emission. Observations of the Galactic ridge in the hard X-ray range with GINGA (Yamasaki et al. 1997) and RXTE (Valinia and Marshall 1998) indicate that the soft spectrum below 200 keV extends down to about 10 keV energy, though the best spectral fit between 15 keV and 150 keV gives a photon index of $\alpha = 2.3$.

A hadronic origin for the hard X-ray/soft $\gamma$-ray continuum via inverse and secondary bremsstrahlung is excluded by the stringent observational limits on the flux of nuclear $\gamma$-ray lines and $\pi^0$-decay $\gamma$-rays from the inner Galaxy (Pohl 1998). Therefore the $\gamma$-ray continuum emission in this energy band is most likely electron bremsstrahlung in the interstellar medium. The power required in low energy (< 10 MeV) cosmic ray electrons to produce a given amount of bremsstrahlung is a fixed quantity that depends only on the energy spectrum of the radiating electrons and weakly on the ionization state of the interstellar medium. Attributing this power input to injection in cosmic ray electron sources, it has been estimated that, integrated over the whole Galaxy, a source power of about $4 \times 10^{41}$ erg s$^{-1}$ (Skibo and Ramaty 1993) or, if the bremsstrahlung emission extends down to photon energies of 10 keV, up to $\sim 10^{43}$ erg sec$^{-1}$ (Skibo, Ramaty and Purcell 1996) in low energy
(<10 MeV) electrons is required, to retain sufficient electrons in the face of severe Coulomb and ionization losses. This electron power exceeds the power supplied to the nuclear cosmic ray component by at least an order of magnitude. The energy losses of the required large population of low energy electrons would be more than adequate to account for the observed hydrogen ionization rate in the interstellar medium (Valinia and Marshall 1998). Proving the truly diffuse nature of the galactic continuum emission below 1 MeV is of utmost importance in pinning down the most relevant particle acceleration process and to understand the interstellar medium ecosystem.

Recently, the extension of the bremsstrahlung continuum emission to these low energies has been attributed to the existence of in-situ stochastic electron acceleration by the interstellar plasma turbulence (Schlickeiser 1997; Schlickeiser and Miller 1998), rather than to the existence of a second electron source component. This turbulence with a measured energy density of $\simeq 4 \times 10^{-14}$ erg cm$^{-3}$ (Minter and Spangler 1997) is an important additional energy source of cosmic ray particles.

The $\gamma$-ray spectrum at high energies
The spatial and spectral distributions of the diffuse emission within $10^\circ$ of the Galactic plane have recently been compared with a model calculation of this emission which is based on realistic interstellar matter, photon distributions and dynamical balance (Hunter et al. 1997). The distribution of the total intensity above 100 MeV agrees surprisingly well with the model predictions. However, at higher energies, above 1 GeV, the model systematically underpredicts the $\gamma$-ray intensity.
If the model is scaled up by a factor 1.6, the model prediction and the observed intensity above 1 GeV agree well. This deficit can be explained neither by a possible miscalibration of EGRET, nor by spectral changes in the nucleonic $\pi^0$-decay emission component (Mori et al. 1997), nor by unresolved point sources like pulsars (Pohl et al. 1997b).

The diffuse model deficit above 1 GeV is visible also at higher latitudes, e.g. in the plots of observed intensity versus Galactic diffuse model shown in the paper of Sreekumar et al. (1998). Uncritical use of the nominal Galactic diffuse model may therefore lead to apparent $\gamma$-ray excesses at higher latitudes, which then may be mistaken as evidence for a $\gamma$-ray halo of exotic origin.

Thus the model displays a deficit of $\sim 40\%$ of the total observed emission which depends, if at all, only weakly on location. One feature of the models is the relatively soft electron injection spectral index of $s=2.4$ (Skibo 1993), which is required to account for the local electron spectrum above 50 GeV. Consequently at energies above 1 GeV, around 90\% of the model intensity is due to $\pi^0$-decay (i.e. hadronic processes) and only 10\% is due to interactions of electrons.

The recent detections of non-thermal X-ray synchrotron radiation from the four supernova remnants SN1006 (Koyama et al. 1995), RX J1713.7-3946 (Koyama et al. 1997), IC443 (Kehohe et al. 1997), and Cas A (Allen et al. 1997), and the subsequent detection of SN1006 at TeV energies (Tanimori et al. 1998) and flux levels according to theoretical predictions (Pohl 1996), support the hypothesis that Galactic cosmic ray electrons are accelerated predominantly in SNR. It has been shown that, if this is indeed the case, the local electron spectra above 30 GeV are variable on time scales of about $10^5$ years (Pohl and Esposito 1998). This variability stems from the Poisson fluctuations in the number of SNR in the solar vicinity within a certain time period. While the electron spectra below 10 GeV are stable, the level of fluctuation increases with electron energy, and above 100 GeV the local electron flux is more or less unpredictable.

Considering this time variability, an electron injection index of $s=2.0$ is consistent with direct particle measurements if SNR are the dominant source of cosmic ray electrons. While being entirely consistent with the local electron flux, and with the radio synchrotron spectrum towards the North Galactic Pole, the leptonic contribution to the diffuse Galactic $\gamma$-ray emission above 1 GeV in the Galactic plane would increase to 30-48\% of the total observed intensity for an injection index of $s=2.0$, depending on the assumed spatial distribution of SNR and on whether some dispersion of injection spectral indices is allowed (Pohl and Esposito 1998). An electron injection index of $s=2.0$ may therefore explain the bulk of the observed $\gamma$-ray excess over that predicted by the Hunter et al. model.

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