The Extragalactic Diffuse Gamma-Ray Emission

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Abstract. The all-sky surveys in γ-rays by the imaging Compton telescope (COMPTEL) and the Energetic Gamma Ray Experiment Telescope (EGRET) on board the Compton Gamma Ray Observatory for the first time allows detailed studies of the extragalactic diffuse emission at γ-ray energies greater 1 MeV. A preliminary analysis of COMPTEL data indicates a significant decrease in the level of the derived cosmic diffuse emission from previous estimates in the 1–30 MeV range, with no evidence for an MeV-excess, at least not at the levels claimed previously. The 1–30 MeV flux measurements are compatible with power-law extrapolation from lower and higher energies. These new results indicate that the possible contributions to the extragalactic emission from processes that could explain the MeV-excess, such as matter-antimatter annihilation, is significantly reduced. At high energies ($>$ 30 MeV), the extragalactic emission is well described by a power law photon spectrum with an index of –(2.10±0.03) in the 30 MeV to 100 GeV energy range. No large scale spatial anisotropy or changes in the energy spectrum are observed in the deduced extragalactic emission. The most likely explanation for the origin of this extragalactic γ-ray emission above 10 MeV, is that it arises primarily from unresolved γ-ray-emitting blazars. The consistency of the average γ-ray blazar spectrum with the derived extragalactic diffuse spectrum strongly argues in favor of such an origin. The extension of the power law spectrum to 100 GeV implies the average emission from γ-ray blazars extends to 100 GeV.

INTRODUCTION

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 [55]. The first all-sky survey in low and medium energy γ-rays (1 MeV–30 MeV) has been carried out by COMPTEL and at higher energies (>30 MeV) by EGRET on board the

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Compton Observatory satellite (CGRO). 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 emission and our understanding of its origin. The measurement of the extragalactic γ-ray emission is made difficult by the very low intensity of the expected emission and the lack of a spatial or temporal signature to separate the cosmic signal from other radiation. The measured diffuse emission along any line-of-sight, could be composed of a Galactic component arising from cosmic-ray interactions with the local interstellar gas and radiation, an instrumental background, and an extragalactic component. In the 1 to 10 MeV band, diffuse studies have been traditionally complicated by difficulties in fully accounting for the instrumental background. At higher energies (E>10 MeV), the results are subject to difficulties in accurately accounting for the Galactic diffuse emission.

Before the launch of CGRO, the γ-ray spectrometer flown aboard three Apollo flights [68] and numerous balloon-borne experiments [72] [48], showed the presence of a 'bump' -like feature in the few MeV range that was in excess of the extrapolated hard X-ray continuum. Although the measured intensities varied widely among the numerous experiments, most showed some level of an MeV-excess. It was recognized as early as 1972, that cosmic-ray induced radioactivity is the most dominant source of background in the MeV energy range [19]. Recent results from the COMPTEL [28] [29] and the Solar Maximum Mission (SMM) [70] experiments indicate no evidence for an MeV-bump, at least not at the levels previously reported.

At higher energies (>35 MeV), the SAS-2 satellite [16] provided the first clear evidence for the existence of an extragalactic γ-ray component. This emission, seen as an excess over the the strong Galactic diffuse radiation, was uncorrelated with the column density of matter and was therefore interpreted as being extragalactic in origin [17]. The recent EGRET results [52] extend the high energy measurement to an unprecedented $\sim$100 GeV. The emission above 30 MeV is well represented by a single power-law of index -2.1 and shows no significant departure from isotropy.

The origin of the extragalactic γ-ray emission has proved to be an elusive goal for theorists over the years. Prior to CGRO, even the question as to whether the radiation is from a truly diffuse process or is, in fact, the superposition of radiation from a large number of extragalactic sources has been difficult to answer. At MeV energies, theoretical efforts to explain the emission, were constrained by the need to explain the MeV excess. The absence of a source class at these energies, whose spectrum displayed this characteristic signature, made this particularly difficult. At higher energies, the SAS-2 and COS-B experiments together, detected one extragalactic source, 3C273, suggesting active galactic nuclei (AGN) as a viable source class that could contribute to the diffuse background [3] [30]. More recently, the detection of >50 γ-ray blazars by EGRET and their spectral properties, have been used to improve theoretical calculations of the diffuse γ-ray emission from blazars.

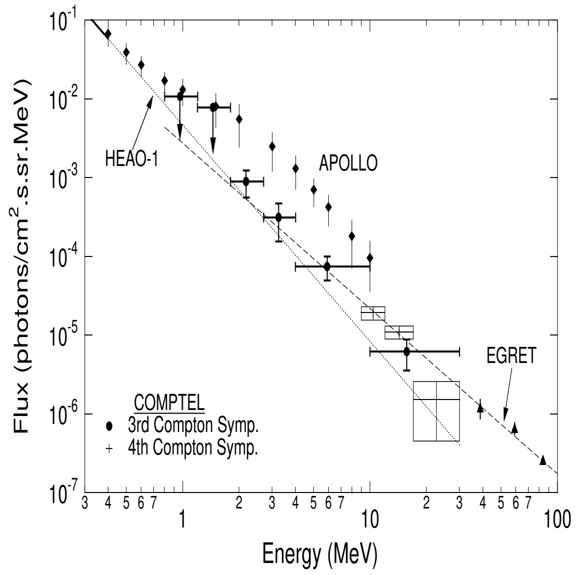

FIGURE 1. COMPTEL results (Kappadath et al. 1996, 1997): The HEAO-1 data are from Kinzer et al. (1997) and the Apollo measurements are from Trombka et al. (1977)

Here we review the current observational and theoretical understanding of the diffuse extragalactic γ-ray emission above 1 MeV. Recent analysis results from the instruments on the Compton Gamma Ray Observatory are summarized. For a more detailed discussion on the COMPTEL and EGRET results, see Kappadath et al. (1996, 1997) [28] [29] and Sreekumar et al. (1997) [52] respectively. Finally, the implications of these new findings on the origin of the extragalactic diffuse emission, are discussed.

RECENT RESULTS FROM CGRO

COMPTEL results (1–30 MeV)

The COMPTEL diffuse emission spectrum is constructed from high-latitude observations, by first subtracting the instrument background and then attributing the residual flux to the extragalactic diffuse radiation. The instrumental background is in general composed of 'prompt' and 'long-lived' components.

The prompt background is instantaneously produced by proton and neutron interactions in the spacecraft. Hence the prompt background refers to the component that modulates with the instantaneous local cosmic-ray flux. The prompt background is seen to vary linearly with the veto-scalar-rates (charge-particle shield rates). Assuming that zero veto-scalar-rate corresponds to zero cosmic ray flux, a linearly extrapolation is used to compute the prompt

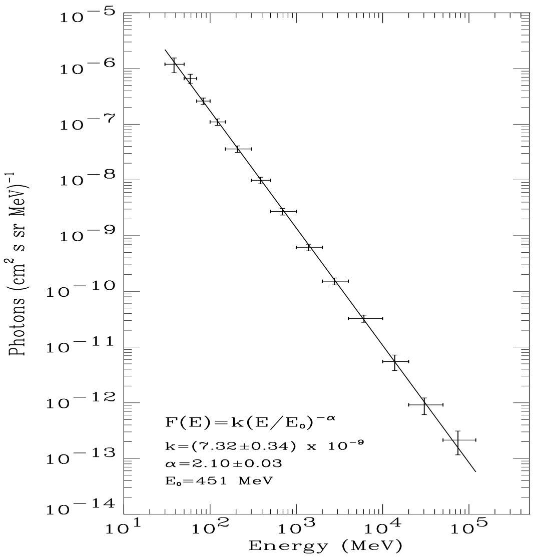

FIGURE 2. EGRET results: The extragalactic diffuse emission spectrum >30 MeV (Sreekumar et al. 1997)

background contribution.

The long-lived background events are due to de-excitation photons from activated radioactive isotopes with long half-lives ($\tau_{1/2} > 30$ sec). Their decay rate is not directly related to the instantaneous cosmic-ray flux because of the long half-lives. The long-lived background isotopes are identified by their characteristic decay lines in the individual detector spectra. Monte Carlo simulation of the isotope decay are used to determine the COMPTEL detector response. The measured energy spectrum is used to determine the absolute contribution of each of the long-lived background isotopes.

The diffuse flux measured by COMPTEL, refers to the total γ-ray flux in the field-of-view ($\sim$1.5 sr) derived from high-latitude observations. It is important to point out that it includes flux contribution from the Galactic diffuse emission and γ-ray point sources in the field of view. It is important to point out that the COMPTEL results below $\sim$ 9 MeV are still preliminary. The 2–9 MeV flux is significantly lower than pre-COMPTEL measurements. They show no evidence for a MeV-excess, at least not at the levels reported previously. Only upper-limits are claimed below $\sim$2 MeV. Recent improvements in the 9-30 MeV spectrum [29], are shown in figure 1. The 9–30 MeV flux is consistent with the previous measurements (mostly upper-limits) and also compatible with the extrapolation of the EGRET spectrum [52] to lower energies.

In examining the isotropic nature of the diffuse radiation, a simple comparison shows that the measured 9–30 MeV spectrum from the Virgo and South Galactic Pole regions are consistent with each other [29].

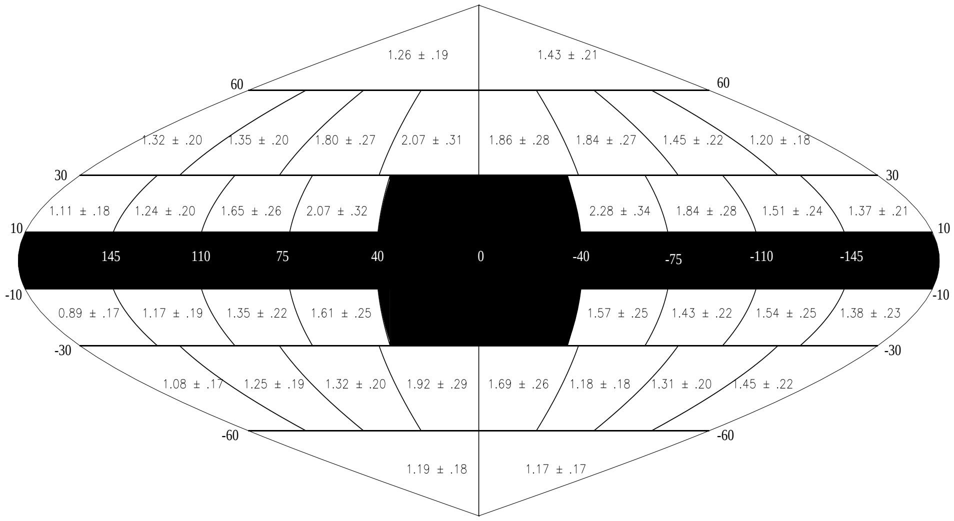

FIGURE 3. The distribution of extragalactic flux (E>100 MeV). The shaded region containing the Galactic plane is excluded due to extreme dominance of the Galactic emission and the region centered on the Galactic Center and extending towards ±30°in latitude is excluded due to difficulties in modeling all of the Galactic emission (Sreekumar et al. 1997).

EGRET results (30 MeV – 100 GeV)

In the EGRET energy range, the primary source of error in estimating the extragalactic emission arises from uncertainties in the Galactic diffuse emission model. In order to derive the extragalactic emission without being sensitive to the Galactic model used, the following approach is adopted for the EGRET data. The observed emission ($\mathrm{I}_{observed}$) is assumed to be made up of a Galactic ($\mathrm{I}_{galactic}$) and an extragalactic component ($\mathrm{I}_{extragalactic}$).

$$I_{observed}(\mathrm{l,b,E}) = \mathrm{I}_{extragalactic} + B \times I_{galactic}(\mathrm{l,b,E})$$

The slope, 'B' of a straight line fit to a plot of observed emission versus the Galactic model gives an independent measure for the normalization of the input Galactic model calculation. The primary processes that produce the observed Galactic diffuse γ-rays are: cosmic-ray nucleons interacting with nucleons in the interstellar gas, bremsstrahlung by cosmic-ray electron, and inverse Compton interaction of cosmic-ray electrons with ambient low-energy interstellar photons [57]. The Galactic diffuse emission falls of rapidly at higher latitudes, making high-latitude observations, ideally suited to study the extragalactic emission. The possible contribution to the Galactic diffuse emission from unresolved point sources such as pulsars, is uncertain with estimates ranging from a few percent to almost 100% depending on the choice of many model parameters such as the birth properties of pulsars [1]. The evidence for a pion 'bump' (from neutral pion decay) in the Galactic diffuse

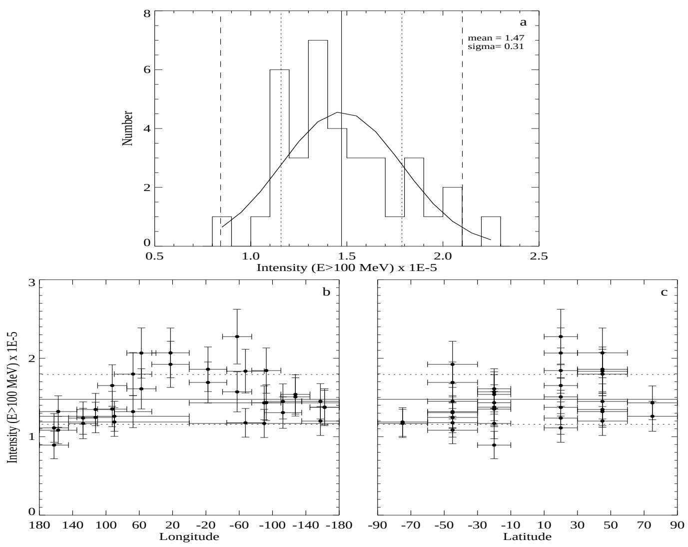

FIGURE 4. The all-sky distribution of integral flux (E>100 MeV) in units of photons $(cm^2\text{-s-sr})^{-1}$ (Sreekumar et al. 1997). (a) Gaussian fit to the flux histogram showing the mean (solid), 1σ (dotted) and 2σ (dashed) confidence intervals; (b)&(c) Intensity values plotted over longitude and latitude respectively. The longitude distribution shows slightly larger intensity values within $\pm 60\ ^\circ$

spectrum [25] can be used to set an upper limit for the contribution from unresolved sources at <50%.

Preliminary results on the extragalactic spectrum above 30 MeV were reported by Kniffen et al. (1996) [34], using the Galactic diffuse model of Hunter et al. (1997) [25] and its high-latitude extension discussed by Sreekumar et al. (1997) [52]. Earlier, Osborne, Wolfendale and Zhang (1994) [44] had shown that the spectrum derived from EGRET is well represented by a power-law of index (2.11 ± 0.05). Even though this was within errors of the previous best estimate of ($2.35^{+0.4}_{-0.3}$) from the SAS-2 experiment [67], the EGRET measurements clearly demonstrated the existence of a well defined, harder power-law spectrum. Independent analysis by Chen, Dwyer and Kaaret (1996) [6] also yielded a spectral index of (2.15 ± 0.06) and an integral flux above 100 MeV of $(1.24\pm0.06)\times10^{-5}$photons $cm^{-2}s^{-1}$ $sr^{-1}$for E>100 MeV. More recently, Sreekumar et al. (1997) [52] using $\sim$ the first 4 years of EGRET observations, carried out a more detailed and careful analysis of the intensity and spectral shape in different regions covering the full sky and for the first time extended the spectrum up to an unprecedented 100 GeV. The differential photon spectrum of the extragalactic emission averaged over the sky is well fit

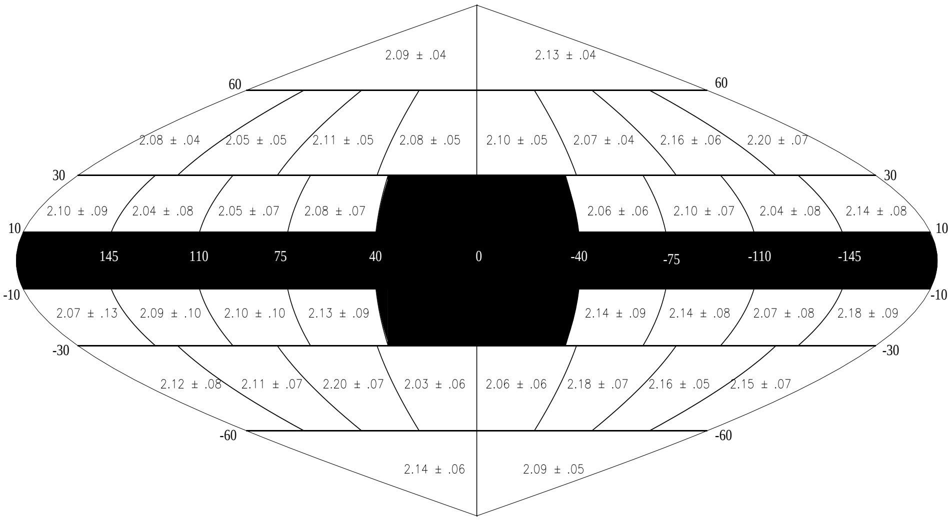

FIGURE 5. The distribution of spectral indices assuming a single power-law fit to the extragalactic spectrum above 30 MeV (Sreekumar et al. 1997).

by a power law with an index of $-(2.10{\pm}0.03)$. The spectrum was determined using data from 30 MeV to 10 GeV; however as shown in Figure 2, the differential photon flux in the 10 to 20 GeV, 20 to 50 GeV, and 50 to 120 GeV energy intervals are also consistent with extrapolation of the single power law spectrum. The integrated flux from 30 to 100 MeV is $(4.26{\pm}0.14){\times}10^{-5}$photons cm^{-2}s^{-1} sr^{-1}and that above 100 MeV is $(1.45{\pm}0.05){\times}10^{-5}$photons cm^{-2}s^{-1} sr^{-1}.

With the availability of high quality data from CGRO, one can for the first time, address the isotropic nature of the extragalactic emission. The derived integral fluxes in 36 independent regions of the sky are shown in Figure 3, with the values ranging from a low of $(0.89{\pm}0.17){\times}10^{-5}$photons cm^{-2}s^{-1} sr^{-1}to a high of $(2.28{\pm}0.34){\times}10^{-5}$photons cm^{-2}s^{-1} sr^{-1} [52]. The shaded area in the figure represents the region where the Galactic diffuse emission is dominant and hence not included in the analysis. Figure 4a shows a histogram of integral flux values, overlayed by a Gaussian fit assuming equal measurement errors. The Gaussian fit yields a mean flux above 100 MeV of $1.47{\times}10^{-5}$photons cm^{-2}s^{-1} sr^{-1}with a standard deviation of $0.33{\times}10^{-5}$photons cm^{-2}s^{-1} sr^{-1}consistent with the all-sky calculation. To further examine the spatial distribution, Figure 4b and 4c shows the same data plotted against Galactic longitude and latitude respectively. No significant deviation from uniformity is observed in the latitude distribution; however as a function of longitude, there appears to be an enhancement in the derived intensities towards l$\sim$20°, primarily due to a few regions on the boundary of the excluded Galactic center region. This could arise from unaccounted extended

Galactic diffuse emission. If one excludes the inner regions of the Galaxy ($|r|$ <60°; r=angle made with the direction of the Galactic center), the mean flux is 1.36×10^{-5}photons cm^{-2}s^{-1} sr^{-1}above 100 MeV. Thus the measured extragalactic flux is consistent within errors to a uniform sky distribution in regions outside the inner Galaxy.

Figure 5 shows the distribution of the derived spectral indices from fits to data from 36 independent regions of the sky. The power law indices vary from –(2.04±0.08) to –(2.20 ±0.07) and show no systematic deviations from the value of –(2.10±0.03), derived from the all-sky analysis.

ORIGIN OF THE EXTRAGALACTIC γ-RAY EMISSION

A large number of possible origins for the extragalactic diffuse γ-ray emission have been proposed over the years (e.g. [56] [18] [20]). The key to understanding the origin of the extragalactic emission may lie in the realization

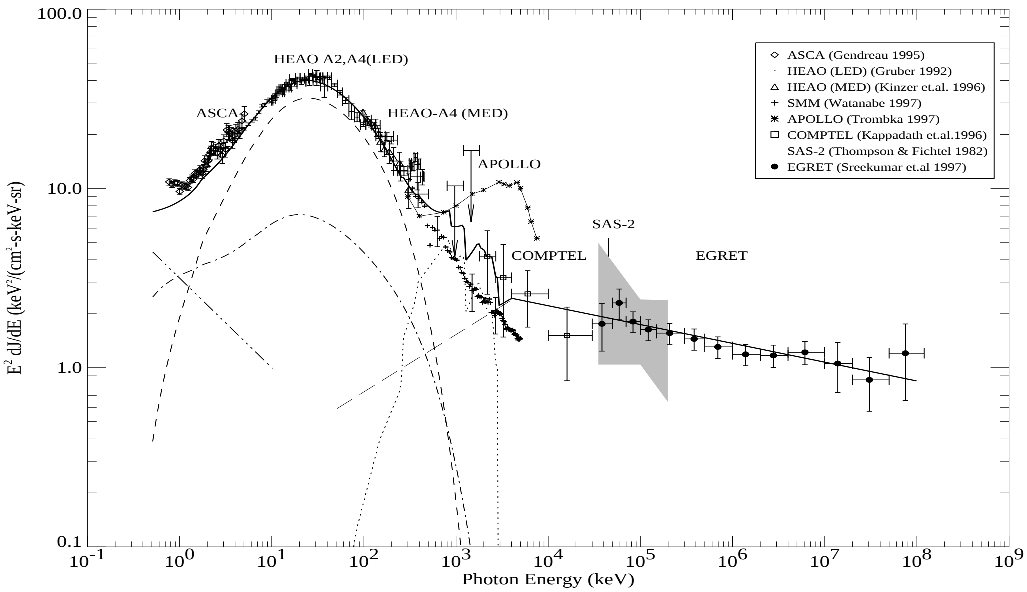

FIGURE 6. Multiwavelength spectrum from X-rays to γ-rays including the revised 1σ upper limits from the Apollo experiment (Trombka 1997). The estimated contribution from Seyfert 1 (dot-dashed), and Seyfert 2 (dashed) are from the model of Zdziarski(1996); steep-spectrum quasar contribution (dot-dot-dashed) is taken from Chen et al. (1997); Type Ia supernovae (dot) is from The, Leising and Clayton (1993). the average blazar spectrum breaks around 4 MeV (McNaron-Brown et al. 1995) to a power law with an index of ∼–1.7. The thick solid line indicates the sum of all the components.

that it may be composed of a number of different components having different origins and that these components in turn may dominate the observed emission only in specific energy ranges (Figure 6). For example, the putative matter-antimatter component would only be important in the energy range between ~ 1 MeV and ~ 100 MeV. The unresolved source models must also be broken up into different source classes and energy ranges. We discuss separately the two distinct possibilities, a truly diffuse origin or the superposition of unresolved sources.

Diffuse origin

The physics of the truly diffuse physical processes which might be involved have been discussed previously [53] [55] [56]. Among those that could potentially contribute to the emission, particularly between 1 and 100 MeV, the most significant could be matter-antimatter annihilation in a globally baryon-symmetric cosmology based on grand unified theories and early universe physics [54] [58]. In the light of recent COMPTEL and SMM data, it appears more likely that the contribution from such a process (if any) is significantly lower than previously reported. Around $\sim$1 MeV, it has been suggested that a significant fraction of the emission could be made up of γ-ray production in type Ia and type II supernovae primarily via lines from the decay of ^{56}Ni $\rightarrow ^{56}$Co $\rightarrow ^{56}$Fe and from ^{26}Al, ^{44}Ti, and ^{60}Co [66] [70]. However, uncertainties associated with the existing observational data in the 1–30 MeV makes it difficult to estimate the contributions from the different proposed processes.

Diffuse processes that have been proposed to explain the high-energy emission include , primordial black hole evaporation [46] [24], million solar-mass black holes which collapsed at high redshift (z$\sim$100) [22], and some exotic source proposals, such as annihilation of supersymmetric particles [50] [47] [27]. All of these theories predict continuum or line contributions that are unobservable above 30 MeV with EGRET.

Unresolved Point Sources

Normal Galaxies

Models based on discrete source contributions have considered a variety of source classes. Normal galaxies might at first appear to be a reasonable possibility for the origin of the diffuse radiation since they are known to emit γ-rays and to do so to very high γ-ray energies [51] [25]. Previous estimates [35] [65] [36] [17] have shown that the intensity above 100 MeV expected from normal galaxies is only about 3% to 10% of what is observed. Further and perhaps even more significant, the energy spectrum of the Galactic diffuse γ-rays is significantly different from the extragalactic diffuse spectrum, being harder at low energies (<1000 MeV) and considerably steeper in the 1 to 50 GeV region [15]. Dar and Shaviv (1995) [12] have suggested that emission arises from cosmic ray interaction with intergalactic gas in groups and clusters of galaxies. Although the authors claim that this proposed explanation leads to a higher intensity level, it is still in marked disagreement with the measured energy spectrum [62]. Finally, cosmic ray electrons and protons that leak out into the intergalactic space could upscatter the CMB to γ-ray energies. Chi and Wolfendale (1989) [10] and Wdowczyk and Wolfendale (1990) [71] have shown these contributions to be not significant.

Active Galaxies: Seyferts

It has been postulated for over two decades by a large number of authors that active galactic nuclei (AGN) might be the source of the extragalactic γ-ray diffuse emission (e.g. [3] [30]). However, prior to the launch of CGRO, only a handful of these objects were claimed to be detected at energies above 1 MeV. With the detection of a large number of AGN with instruments on board CGRO, it was natural to consider that the fainter unresolved sources could collectively make up the observed extragalactic γ-ray emission. Using data from the OSSE experiment, it has been shown that the average Seyfert galaxy spectrum, is characterized by an exponentially falling continuum (e-folding energy $\sim$100 keV) together with a Compton reflection component which contributes mainly in the 10-50 keV band [26] [74]. However, none have been detected above 1 MeV [39] [37]. The generally accepted reason for this is that the photon fields within AGN are so intense that pair production prevents the higher energy γ-radiation from escaping [64] [73] [13]. Thus, although Seyfert galaxies may provide a substantial contribution to the X-ray background, and may also provide the dominant contribution to the high energy neutrino background [59] [60], these objects are not expected to be important sources of high energy γ-radiation. Another sub-class of AGNs, the 'MeV-blazars', have been shown to exhibit peak power at MeV energies [4] [5]. Comastri, Girolamo and Setti [11] have discussed the possible contribution to the diffuse emission from these objects. Since at present, only $\sim$1% of the γ-ray blazars show an MeV excess, observationally, it suggests that MeV-blazars may not be a significant contributor to the extragalactic diffuse emission.

Active Galaxies: Blazars

While radio-quiet AGN do not qualify as significant medium or high energy γ-ray sources, the EGRET observations showed the presence of a class of AGN, characterized by strong time variability at many wavelengths including

γ-rays, flat radio spectrum and often exhibit strong polarization and (or) superluminal motion. These are the BL Lac objects and the flat spectrum radio quasars (FSRQ) which together have been classified as 'blazars'. The EGRET team has now reported the detection of over 50 blazars [41] [43]. Of these six have been detected at COMPTEL energies as well. It is believed that most of these objects generally have jets beaming their emission toward us. It is natural to assume that, since the jets are optically thin to high energy γ-rays and since beaming in the jets can produce a large enhancement in the apparent γ-ray luminosity relative to unbeamed components, therefore, the γ-ray emission from these objects is probably beamed and originates in the jets. This hypothesis is supported by the rapid γ-ray time variability observed in many blazars (for eg. 3C279 [33]).

McNaron-Brown et al. (1995) [40] examined the multiwavelength spectra of the six blazars detected by OSSE, COMPTEL and EGRET. Using this data set, one can derive an 'average' blazar spectrum characterized by a broken power-law with a break at $\sim$4 MeV ([52]). The derived average differential photon spectral index below 4 MeV is determined to be about -1.7 and above 4 MeV to be equal to the average spectral index of EGRET detected blazars ($\sim$$-2.1$). However below 10 MeV, the blazar contribution alone is not sufficient to explain the observed extragalactic emission. Thus, the true origin of the emission in this energy range is not yet fully understood. We note that while the EGRET spectrum represents the extragalactic diffuse radiation, the COMPTEL spectrum refers to the total γ-ray flux from high-latitude observations (including contribution from the Galactic diffuse and γ-ray point sources in the FOV of $\sim$1.5 sr).

One of the more important pieces of evidence in favor of the blazar origin of the high-energy portion of the diffuse spectrum is the spectrum itself. Both the spectrum reported here and the average spectrum of blazars may be well represented by a power law in photon energy. The spectral index determined here for the diffuse radiation is $-(2.10\pm0.03)$, and the average spectral index of the observed blazars is $-(2.15\pm0.04)$ [43] These two numbers are clearly in good agreement. A standard cosmological integration of a power law in energy yields the same functional form and slope. Considering the new, well determined γ-ray spectrum, this argues strongly that the bulk of the observed extragalactic γ-ray emission can be explained as ordinating from unresolved blazars.

In order to estimate the intensity of the diffuse radiation from blazars, knowledge of the evolution function is needed, as well as the intensity distribution of the blazars. Two approaches have been utilized to determine the γ-ray evolution. One way is to assume that the evolution is similar to that at other wavelengths. The other alternative is to deduce the evolution from the γ-ray data itself and hence have a solution that depends only on the γ-ray results. The advantage of the former is that, if the assumption of a common evolution is correct, an estimate with less uncertainty is obtained. The positive aspect of the latter is that there is no assumption of this kind, but the uncertainty in the calculated results is relatively large because of the small γ-ray blazar sample.

Several authors have estimated the contribution from blazars using the first approach described above [45] [61] [49] [15] [63] [31] where one accepts the proposition that the evolution function determined from the radio data may be applied to the γ-ray-emitting blazars. Furthermore, the recent work of Mukherjee et al. (1997) [43] shows that there is general agreement within uncertainties between the radio and high-energy γ-ray redshift distributions of both types of blazars, i.e. flat-spectrum radio quasars and BL Lacs. However, a word of caution seems appropriate, since it should be pointed out that the degree and nature of the correlation between the radio and γ-ray emission is still being debated [45] [42] [38]. Most of these calculations show that all or most of the observed mission can be explained as originating from unresolved blazars. Stecker and Salamon (1996) [63] instead of assuming a mean γ-ray spectral index, used the distribution of the observed spectral indices in their calculation. This introduces a curvature in the spectrum; the steep spectrum sources contributing more at lower energies ($<$500 MeV) and the flat-spectrum sources dominating the emission at higher energies. This is consistent with the curvature in the spectrum reported by Osborne, Wolfendale and Zhang (1994) [44]. However recent instrumental corrections to the 2-4 GeV energy range [14] and the extension of the spectrum to 100 GeV, have weakened any evidence for such a curvature in the spectrum.

Chiang et al. (1995) [8] used the second approach by using the γ-ray blazar data to deduce the evolution function. They used the V/Vmax approach in the context of pure luminosity evolution to show that there was indeed evolution of the high-energy γ-ray emitting blazars and found that the implied evolution is similar to that seen at other wavelengths. However, recent work of Chiang and Mukherjee (1997) [9] argue that an improved calculation of the lower end of the de-evolved luminosity function indicates that only $\sim$25% of the observed emission is made up of unresolved blazars. As stated before, the limited sample of detected γ-ray blazars results in larger uncertainty in the above calculation. Furthermore, Stecker and Salamon (1996) [63] and Kazanas and Perlman (1997) [31] concluded that EGRET has preferentially detected those blazars that were in 'flaring' states. Thus there is a clear need for a much improved evaluation of the true γ-ray luminosity function. The expected detection of a large number of sources using a future more sensitive γ-ray instrument such as GLAST, could make this possible.

If the hypothesis that the general diffuse radiation is the sum of the emission of blazars is accepted, there is an interesting corollary. The spectrum of the measured extragalactic emission implies the average energy spectra of blazars extend to at least 50 GeV and maybe up to 100 GeV without a significant change in slope. Most of the measured spectra of individual blazars only extend to several GeV and none extend above 10 GeV, simply because the intensity is too weak to have a significant number of photons to measure. Intergalactic absorption does not have much effect at this energy except for blazars at relatively large redshift, and, in any case would steepen the spectrum at high energies. Hence, the continuation of the single power law diffuse spectrum up to 100 GeV strongly suggests that the source spectrum also continues without a major change in spectral slope to at least 100 GeV. This conclusion, in turn, implies that the spectrum of the parent relativistic particles in blazars that produce the γ-rays remains hard to even higher energies.

SUMMARY

CGRO observations have lead to a significant advancement in our understanding of the extragalactic γ-ray emission. The recent COMPTEL measurements and SMM results have shown that a significant part of the MeV-excess previously reported around 1–10 MeV, is due to instrumental background events. The new measurements in the 1–30 MeV range are compatible with power-law extrapolations from lower and higher energies. The COMPTEL results on the 9–30 MeV flux represents the first significant detection in this energy range. Above 30 MeV, the EGRET observations have extended the high-energy measurement to an unprecedented $\sim$100 GeV. The 30 MeV to 100 GeV spectrum is well described by a single power-law with spectral index of -2.1. No large scale spatial anisotropy or changes in the energy spectrum is observed in the deduced extragalactic spectrum above 30 MeV. The bulk of the extragalactic emission above 10 MeV appears to arise from unresolved blazars and is supported by the consistency in shape between the two spectra. However, below 10 MeV, the exact nature of the emission is not well understood, partly due to the large uncertainties in the measured diffuse spectrum in this energy range. The average blazar spectrum suggest that only about 50% of the measured emission in the 1–10 MeV range, could arise from blazars. Current observational limits do not provide tight constraints on contributions from additional source classes, or from other truly diffuse processes, making this an important area of investigation for the next generation γ-ray experiments.

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