Proceedings of ICRC 2001: 2546 

ICRC 2001

# Spectral cutoffs in EGRET gamma-ray sources

**O. Reimer**[1,2] **and D. L. Bertsch**[3]

[1]NRC/NASA/GSFC, Code 661, Greenbelt, MD 20771, USA
[2]Now at: Institut für Theoretische Physik, Lehrstuhl IV: Weltraum- & Astrophysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany
[3]NASA/GSFC, Code 661, Greenbelt, MD 20771, USA

**Abstract.** The EGRET instrument has measured detailed photon spectra between 30 MeV and 10 GeV, which are represented by means of single power-law fits for sources in the 3EG catalog. However, various sources show indications of spectral cutoffs at GeV energies, which are poorly represented by such simple fits. In the case of well exposed or bright EGRET sources, a description of spectral cutoffs with more complicated functional forms appears to be applicable. An application for such multicomponent fits should be seen in extrapolations beyond the energies accessible to EGRET, i.e. for detectability studies of low-threshold Imaging Atmospheric Cherenkov Telescopes (IACTs). In cases of unidentified gamma-ray sources positionally coincident with Supernova remnants, the spectral shape beyond power-law extrapolations might observationally explain why such prominent SNRs like $\gamma$ Cygni, IC 443 and CTA1 have not been detected during several observation campaigns performed by IACTs over the last years.

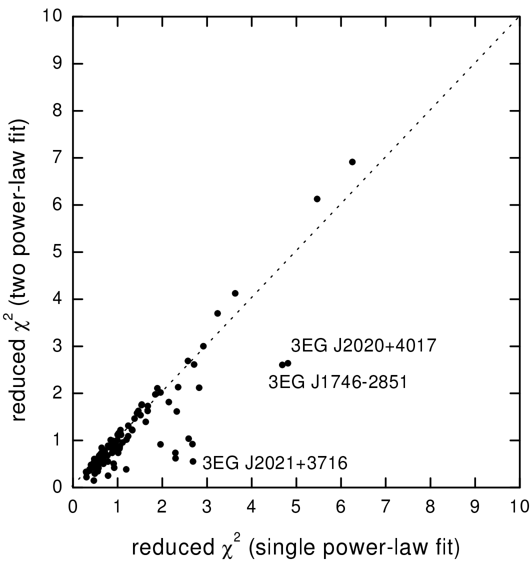


**Fig. 1.** Comparison of the quality of a single power law fit vs. two power law fit by means of reduced $\chi^2$

## 1 Introduction

Spectra of gamma-ray sources in the Third EGRET catalog (Hartman et al. 1999) are consistently represented by spectral indices from single power law fits. In cases of well measured source spectra (i.e. PSR J0633+1746 or PSR B0833-45), there are noticeable deviations from single power-law model fits reported (Fierro et al., 1997). Here we apply higher-order spectral fits as introduced by Bertsch et al. (2000) to the dataset of "steady" unidentified gamma-ray sources used by Gehrels et al. (2000) for a gamma-ray source population study. This subset of the 3EG catalog sources has been used in order to discriminate different source classes among the population of unidentified gamma-ray sources, among other things by means of a comparison in the (simple power law) spectral index. It remains to be investigated, if differences in the average spectral index is a valid separation criteria in terms of the given uncertainties in the spectral fit as well as in respect of more appropriate spectral description using higher order functional forms. Additionally, satellite based gamma-ray measurements still do not connect to the higher neighboring energies, currently accessible using ground-based Cherenkov telescopes. Therefore extrapolations need to be justified, either by appropriate source modeling and/or incorporating of additional observational information, i.e. a quantitative indication of spectral breaks or cut-offs. Here we will especially address cases of unidentified gamma-ray sources positionally coincident with SNRs, as recently recompiled by Romero et al. (1999) and investigated at energies above 300 GeV by Buckley et al. (1998).

*Correspondence to:* O. Reime (olr@egret.gsfc.nasa.gov)

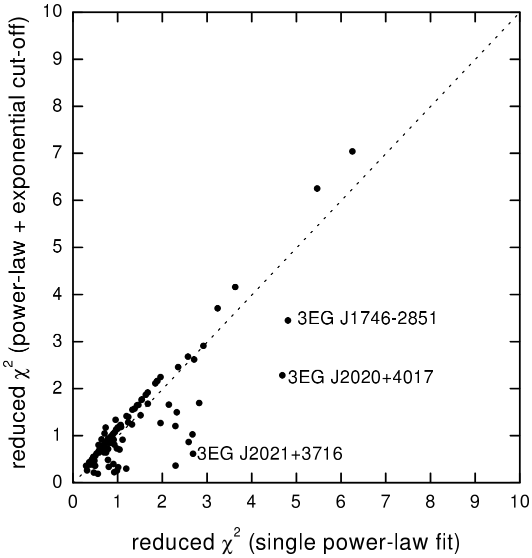


**Fig. 2.** Comparison of the quality of a single power law fit vs. power law fit with exponential cut-off by means of reduced $\chi^2$

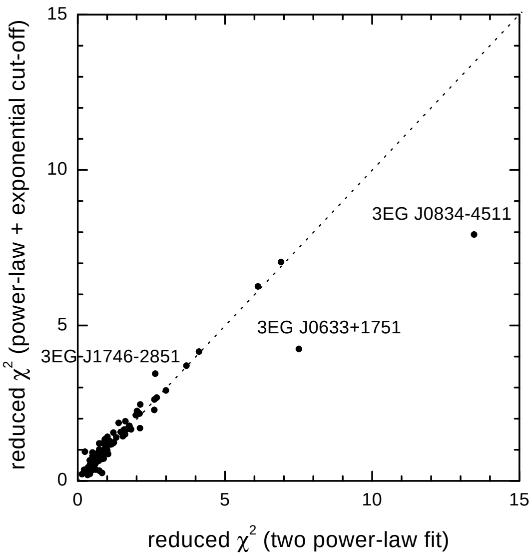


**Fig. 3.** Comparison of the quality of a two power law fit vs. power law fit with exponential cut-off by means of reduced $\chi^2$

## 2 Analysis

The "steady" unidentified sources from the 3EG have been fitted with three functional forms, the standard single power law, two matching power laws, and a power law with exponential cut-off:

$$\frac{\partial J}{\partial E}(E, K, E_0, \lambda) = K\left(\frac{E}{E_0}\right)^{-\lambda} \quad (1)$$

$$\frac{\partial J}{\partial E}(E, K, \lambda_1, \lambda_2) = \begin{cases} K\left(\frac{E}{1\mathrm{GeV}}\right)^{-\lambda_1} (E \leq 1\mathrm{GeV}) \\ K\left(\frac{E}{1\mathrm{GeV}}\right)^{-\lambda_2} (E \geq 1\mathrm{GeV}) \end{cases} \quad (2)$$

$$\frac{\partial J}{\partial E}(E, K, \lambda, E_c) = K\left(\frac{E}{300\mathrm{MeV}}\right)^{-\lambda} exp\left(-\frac{E}{E_c}\right) \quad (3)$$

$E_0$ has been set to the value determined by the EGRET spectral fitting routine as used for the spectral fit given in the 3EG catalog. The location of the break energy has been set to 1000 MeV to keep the number of parameters at a minimum. With each fit, a reduced $\chi^2$ was obtained, followed by an F-Test to decide if there is statistical justification for the transition from a single power law fit to a higher order functional form. In the F-Test, a value of $p < 0.05$ is generally taken as a measure where the higher order fit is warranted. Summed data sets for EGRET observations during CGRO observation cycles 1 to 4 were taken to maximize the available statistics. Spectral studies of EGRET-detected blazars have been previously carried out by Mukherjee et al. (1997), Pohl et al. (1997) and Lin et al. (1999), but never beyond single power law representations. Because spectral hardening has been observed in gamma-ray blazars during outburst (Sreekumar et al., 2001), an overall spectral comparison might not be similarly appropriate for AGN. They will be investigated later for different spectral representation than single power law, whenever possible on shorter timescales than the four years of CGRO observations used here.

## 3 Results

As already reported for the gamma-ray sources close to the Galactic plane in Bertsch et al. (2000), the majority of sources appears to be best represented by single power law fits. This trend has been confirmed for almost all unidentified sources at higher Galactic latitudes. However, only for significantly detected gamma-ray sources the question of departure from a single power law spectrum could be addressed with any chance of a statistically meaningful result. Improvements from non-linear fitting are indicated by $\chi^2$ values lying right of the line in Fig.1 and Fig.2. In Fig.3 the choice of preference of either the two-power law fit or the power law with exponential cut-off is indicated by deviations from the line. Generally, a more complex spectra could only be established if sufficient counts have been observed, rather continuously distributed over the energy range accessible for EGRET, and obviously with bin entries above 1 GeV.
However, the F-Tests do not justify the statistical significance of each individual improvement in $\chi^2$. As indicated in Fig.4 (lines representing the F-Test probability $p = 0.05$), the majority of sources with better representation by non-linear fitting functions are insensitive to the form describing an spectral cuf-off within the currently available data (bottom-left quadrant in Fig.4). A clear indication of a statistically significant preference of either the two power law fit or the power law with exponential cutoff is only given for few individual gamma-ray sources: preference of expo-

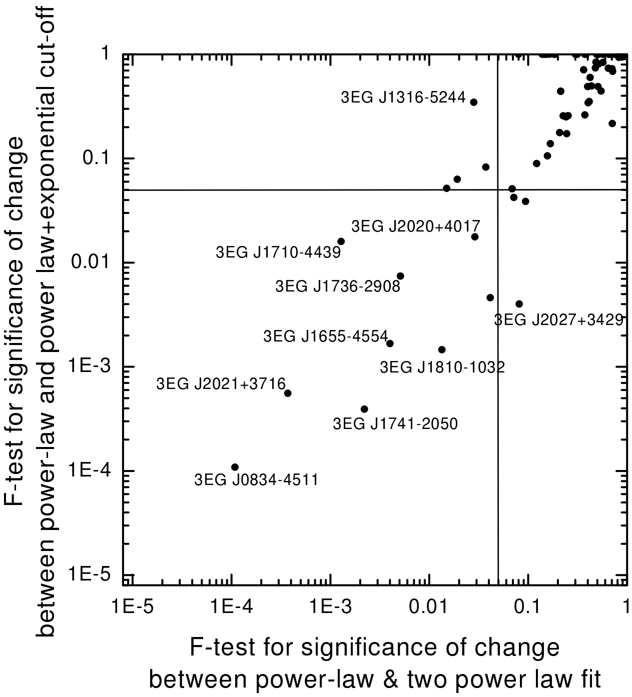


**Fig. 4.** F-Test probabilities for the significance of the improvement obtained by using higher order functional form for fitting the EGRET spectra. Probabilities less than 0.05 indicate that the more complex fitting function is indeed statistically relevant.

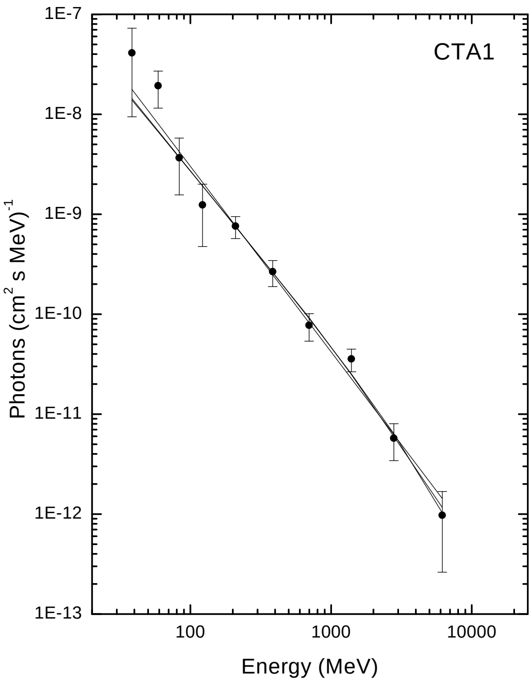


**Fig. 5.** Photon energy spectrum of 3EG J0010+7309, positionally coincident with SNR G119.5+10.2 (CTA 1), shown with three different representations of a spectral fit.

nential cut-off are indicated in bottom-left quadrant, preference of two power law representation in top-left quadrant of Fig.4. Although many gamma-ray sources could not be compared at all to higher order functional fits due to insufficient statistics above the chosen break or cut-off energy, a tendency is indicated and will be probed by GLAST: The better a gamma-ray source has been observed the more significant deviations from the picture of single power fit representations are needed. EGRET seems to occupy a position where instrumental limitations generally do not satisfy more complex interpretations of measured source spectra, however well-measured individual gamma-ray sources already pointing towards structure in the gamma-ray source spectra unable to be adequately represented by a single power-law between 30 MeV and 10 GeV.

Figure 5-8 give examples of individual unidentified sources with different functional representations (Eq. 1-3). All these gamma-ray sources are positionally coincident with SNRs, three of them suspected of resembling the properties of neutron stars in gamma-rays (Brazier et al. (1996), Brazier et al. (1998), Cheng & Zhang (1998)). These candidates are especially interesting because they were studied by ground-based Cherenkov telescopes, however yielding only upper limits so far (Buckley et al., 1998). For interpretation of these results the model of Drury et al. (1994) has been used to extrapolate from the spectrum measured by EGRET. Here we suggest to extrapolate from EGRET observational results using better spectral representations (Petry & Reimer, 2000). This might

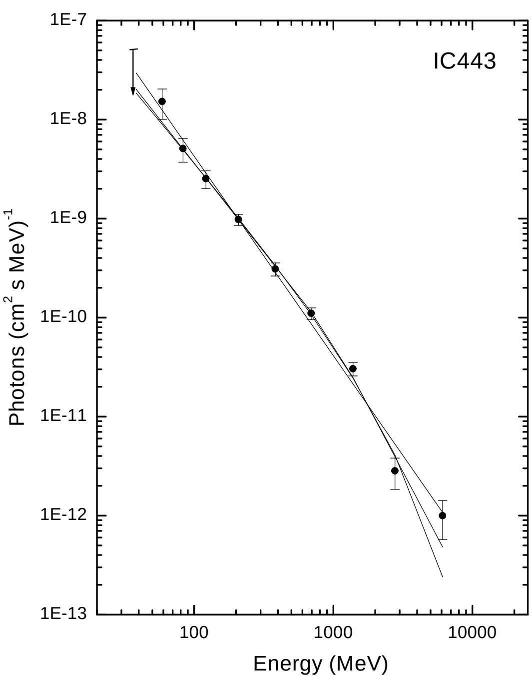


**Fig. 6.** Photon energy spectrum of 3EG J0617+2238, positionally coincident with SNR G189.1+3.0 (IC443), shown with three different representations of a spectral fit.

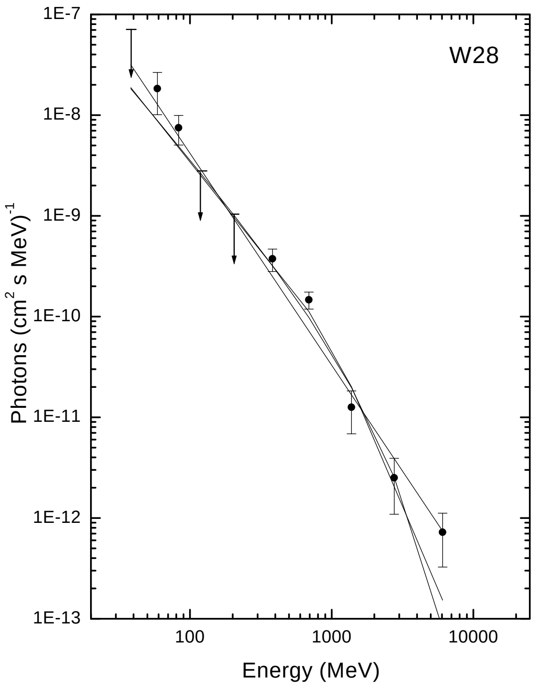


**Fig. 7.** Photon energy spectrum of 3EG J1801-2312, positionally coincident with SNR G6.4-0.1 (W28), shown with three different representations of a spectral fit.

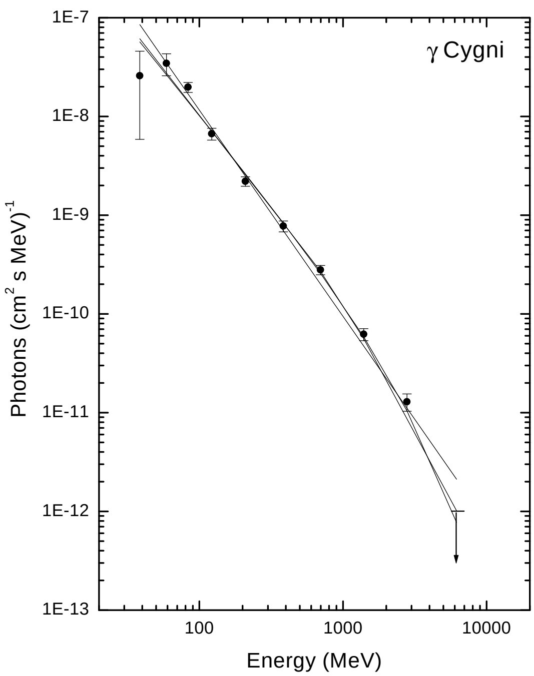


**Fig. 8.** Photon energy spectrum of 3EG J2020+4017, positionally coincident with SNR G78.2+2.1 ($\gamma$ Cygni), shown with three different representations of a spectral fit.

be an alternative or complementing way, especially under the premise that low-threshold Cherenkov telescopes will narrow the energetic gap to existing EGRET measurements.

## References


Fierro, J.M. et al., 1997, ApJ 494, 734

Bertsch, D.L. et al., Proc. 5th Compton Symposium, Portsmouth 1999, AIP 510, 504

Gehrels, N. et. al., 2000, Nature 404, 363

Romero, G.E., Bengalia, P., Torres, D.F., 1999, A&A 348, 868

Buckley, J.H. et al., 1998, A&A 329, 639

Sreekumar, P. et al., Proc. Gamma-Ray Astrophysics 2001, in press

Mukherjee, R. et al., 1997, ApJ 490, 116

Pohl, M.K. et al., 1997, A&A 326, 51

Lin,Y.C. et al., 1999, ApJ 525, 191

Brazier, K.T.S. et al., 1996, MNRAS 281, 1033

Brazier, K.T.S. et al., 1998, MNRAS 295, 819

Cheng, K.S. & Zhang, L., 1998, ApJ 498, 327

Drury, L.O'C., Aharonian, F.A. & Völk, H.J., 1994, A&A 287, 959

Petry, D. & Reimer, O., Proc. Gamma-Ray Astrophysics 2001, in press


*Acknowledgements.* O.R. acknowledges a NAS/NRC Associateship at NASA Goddard Space Flight Center.