A spectral study of gamma-ray emitting AGN

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Abstract. In this paper I investigate the γ-ray spectra of AGN by summing up the intensity and the power-law fit statistic of Quasars and OVV’s and BL Lac’s separately. The spectrum of the average AGN is softer than that of the extragalactic γ-ray background. It may be that BL Lac’s, of which the average has a harder spectrum than Quasars, make up the bulk of the extragalactic background.

We also find cut-offs both at low and at high energies in the spectra of Quasars and OVV’s, however only at the time of γ-ray outbursts. While the cut-off at high energies may have something to do with opacity, the cut-off at low energies may be taken as indication that the γ-ray emission of Quasars is not a one component spectrum.

1. Introduction
Up to the end of 1994 more than 50 extragalactic radio sources have been detected with EGRET as emitters of high-energy γ-rays. The majority of the sources are Quasars and optically violent variables (OVV) and a number are classified as BL Lacertae (BL Lac) objects. Individual γ-ray spectra in the EGRET range can generally be well described by power-laws (von Montigny, this volume). In case of the BL Lac Mrk421 the spectrum extends up to TeV energies (Punch et al. 1992). In this paper we analyse the class-averaged spectra of AGN by summing the observed intensity and the statistic of power-law fits to the observed emission. We also derive the spectrum of the average γ-ray AGN which is to be compared to the spectrum of the diffuse extragalactic background.

2. The average source
Here we have summed all EGRET data of Phases 1,2, and 3. With the standard likelihood techniques we have searched for point sources, of which we can identify 44 as AGN, 11 BL Lac’s and 33 Quasars and OVV’s. For all 44 AGN we have performed a spectral analysis.

There is no cut-off visible in the γ-ray spectra with the possible exception of a weak deficiency below 100 MeV for the Quasars which may be the outer extension of the usual roll-over at a few MeV. We have also searched for systematical deviations from power-law behaviour in the γ-ray spectra of the 44 AGN. For each individual AGN we have fitted a power-law spectrum to the data. The weighted difference between this fit and the measured intensity in the ten en-
ergy bands, i.e. $\chi = (I_{fit} - I)/(\delta I)$, has been summed for all Quasars and BL Lac’s, respectively, to obtain the average deviation. No significant deviations from power-law behaviour in the average AGN spectrum is observed, neither for Quasars and OVV’s nor for BL Lac’s.

### 2.1. The relation to the $\gamma$-ray background

We have summed the observed intensity in ten energy bands to derive the spectrum of the average AGN. This spectrum is what we would get as contribution to the diffuse extragalactic background if the AGN were unresolved. The $\gamma$-ray intensity of all 44 AGN sums up to around 7% of the diffuse background. It is interesting to see that the $\gamma$-ray spectrum of the average BL Lac is harder than that of the average Quasar and OVV (with formal significance 1.7σ). This does not imply that in single viewing periods BL Lac’s have always harder spectra than Quasars. In fact we see a remarkable spread of spectral indices for both classes of objects when individual viewing periods are considered. But this concerns individual sources. The spectrum of the average in both object classes is different, and therefore they contribute with different spectral characteristic to the diffuse $\gamma$-ray background. The average spectrum of all AGN is dominated by that of the Quasars and it differs with 2.7σ significance from that of the observed diffuse extragalactic background (Kniffen et al. 1997) which is similar to the average BL Lac intensity spectrum. Interestingly, the BL Lac’s have on average a much smaller redshift with values between 0.031 and 0.94, while more than 50% of the objects in the Quasar and OVV class have redshifts in excess of 1.0. This indicates that in case of Quasars we observe a fair range of the luminosity function directly, in contrast to the BL Lac case where we see only the tip of the iceberg. In other words, we expect the $\gamma$-ray log $N$/log $S$ distribution of BL Lac’s to peak at lower $\gamma$-ray fluxes than that of Quasars and OVV’s. As a result the contribution of BL Lac’s to the diffuse extragalactic $\gamma$-ray background may be strong despite the small number of directly observed objects. Hence it may be that BL Lac’s provide the bulk of the $\gamma$-ray background.

### 3. The peak spectra

A large fraction of AGN is variable at $\gamma$-ray energies. Any cut-off arising from opacity effects will be more prominent at high flux levels since then the intrinsic photon density of the source is high. We have therefore chosen a subsample of AGN for which at least a moderate level of variability can be found. In total we are left with 26 Quasars and OVV’s and only 6 BL Lac’s. The analysis is now similar to that described in the previous section except that the spectra are not derived on the basis of the summed data of Phases 1-3 but only on data of the viewing periods in which the sources showed the highest flux levels.

There is not very much change compared to the average behaviour in case of BL Lac’s. One has to keep in mind that we are now left with 6 objects and the statistic is not sufficient to distinguish general trends from pathological individuals.

The behaviour of quasars and OVV’s during their peak phase is more interesting. At first we see that the flare spectra are harder than the time-average, at least up to a few GeV. This is a confirmation of a claim by Mücke et al.
Figure 1. The summed power-law fit statistic of the 26 variable Quasars and OVV’s at the time of their peak flux level. Here the power-law fit is based only on the data between 70 MeV and 4 GeV, i.e. omitting the outer energy bands for which a deviation was suspected. The total statistical significance of the spectral breaks is 3.6σ at low energies and 2.5σ at high energies.

(1996) who found a hardening of the γ-ray spectra with increasing flux level for 8 highly variable γ-ray AGN. We also see that at energies below 70 MeV and at energies above 4 GeV the peak spectra show some evidence of a cut-off. To get a better idea of the significance level of the cut-offs we have repeated the power-law fits for the peak phases of quasars and OVV’s under the constraint that now the fit is based on the energy band of 70 MeV to 4 GeV and then extrapolated to calculate the true deviations in the outer energy bands. The result is shown in Fig.1. At energies below 70 MeV there is a deficiency of intensity compared to power-law behaviour with total statistical significance of 3.6σ while at high energies above 4 GeV we observe an intensity deficit with 2.5σ significance. This result is stable with respect to the choice of sources. We have omitted the sources which have less than 6σ significance at the time of flare and the outcome remains unchanged. We have also included secondary flares, i.e. viewing periods in which the sources have been either within 2σ of the peak or have been observed with $S \geq 10^{-6} \text{cm}^{-2}\text{sec}^{-1}$ above 100 MeV, and again the result is unchanged.
We have further tested the reliability of our method by Monte-Carlo simulations. These simulations would detect systematic problems in the analysis tools, which may arise from the small photon numbers both at low and at high $\gamma$-ray energies. We did not detect significant systematic deviations from a Gaussian distribution of the variable $\chi$. Even accounting for calibration uncertainties at low $\gamma$-ray energies the statistical uncertainties are much larger than the systematical uncertainties so that the former are a fair measure of the total uncertainty.

3.1. The cut-off at low energies

Most Quasars show a spectral break at MeV energies. It is, however, questionable whether such an extended spectra turnover is sufficient to account for the observed deficit below 70 MeV, which is a factor 10 higher in energy than the typical break energy. We prefer to interprete the result in the sense that the $\gamma$-ray spectrum of Quasars and OVV’s is not a one component spectrum, but rather the superposition of different emission processes. Simulations show that a low energy cut-off in the injection spectrum of radiating electrons can account for the observed behaviour (Böttcher and Schlickeiser 1996).

3.2. The cut-off at high energies

The fact that we see this cut-off only at flare states, when photon densities are high, points at opacity effects as cause. In case of backscattered accretion disk photons the opacity will sharply increase at a few GeV. If the efficiency of backscattering is high, which is probably the case for Quasars and OVV’s, the optical depth will exceed unity and a cut-off will result. However, correlations between optical depth and the flux at a few 100 MeV will occur only when the $\gamma$-ray outburst is caused by an increased flux of target photons.

One may also think of photon-photon pair production on the high energy end of the self produced synchrotron spectrum. Here a correlation with the flux level can be naturally explained. Simulations show that at least in simple geometries the synchrotron-self-Compton component tends to swamp the high energy end of the synchrotron spectrum (Böttcher, Pohl and Schlickeiser, in prep.), so that there is no natural reason to let this effect become important at a few GeV $\gamma$-ray energy.

Though opacity effects seem to be involved it is not yet clear where the target photons are supposed to come from. Further simulations may help to understand the cut-offs better.

References

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