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A large high-energy gamma-ray flare from the blazar 3C 273

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Abstract. The Compton Gamma-Ray Observatory (CGRO) experiments EGRET and COMPTEL observed the Virgo sky region continuously for 7 weeks between December 10, 1996 and January 28, 1997. The prominent quasar 3C 273 was found to be the brightest source in γ-rays and was significantly detected by EGRET and COMPTEL. The EGRET experiment observed a time-variable flux at energies above 100 MeV, which reached in a 2-week flaring period (December 30, 1996 to January 14, 1997) its highest flux level observed during the CGRO-era. COMPTEL, however, does not observe obvious time variability at energies below $\sim$30 MeV contemporaneous to EGRET. In particular, no flare was observed, indicating that this outburst is solely a high-energy (>100 MeV) phenomenon. The energy spectrum between 3 MeV and 10 GeV is well represented by a simple power-law model. Below 3 MeV a spectral turnover is indicated. Performing spectral analysis for different time periods, we found evidence for a spectral hardening during the flaring period, which is consistent with the flare occurring mainly at the higher energies and with its absence at COMPTEL energies of a few MeV. This may be interpreted as an indication that the emission in the EGRET energy range is dominated by a different radiation mechanism than the MeV emission. We argue that the most likely mechanism for the high-energy flare is inverse-Compton scattering of reprocessed accretion-disk radiation.

Key words: gamma rays: observations — galaxies: active — galaxies: quasars: individual: 3C 273

1. Introduction

Since its discovery as an extragalactic object in 1962 (Schmidt 1963), the quasar 3C 273 is one of the best studied Active Galactic Nuclei (AGN). With a redshift of 0.158 ($\sim$800 Mpc for H_0 = 60 km/s/Mpc) it is relatively close, and by being bright in all wavelength regions from radio to γ-ray energies, it is an excellent candidate for multi-wavelength studies.

After six years of operation, the EGRET experiment aboard CGRO has now detected γ-ray emission from more than 70 AGN at energies above 100 MeV (e.g. Hartman et al. 1999). These observations have dramatically changed our picture of these sources. With the exception of Cen A (Sreekumar et al. 1999), all of them are identified with blazars (e.g. Mattox et al. 1997), the AGN subgroup consisting of either flat-spectrum radio quasars or BL Lacertae objects. Two remarkable γ-ray characteristics of these sources are that 1) they are highly variable down to time scales of a day or even shorter, and 2) that during flaring states the γ-ray luminosity can dominate their bolometric power.

The quasar 3C 273 is one of these blazar-type γ-ray loud AGN. It was first detected at γ-rays by the COS-B satellite at energies above 50 MeV (Swanenburg et al. 1978), and – until the launch of CGRO in 1991 – remained the only identified extragalactic point source at these energies. 3C 273 was redetected at γ-ray energies by the EGRET experiment in 1991 (von Montigny et al. 1993). Analysing the first four years of EGRET data, von Montigny et al. (1997) found a time-variable γ-ray flux, consisting of detections as well as non-detections in individual observational periods. Spectral variability was observed as well, showing the trend of spectral hardening with increasing flux. The third EGRET source catalogue (Hartman et al. 1999) lists 3C 273 with an average flux value of (15.4$\pm$1.8) $\times$ 10^{-8} ph cm^{-2} s^{-1} for energies above 100 MeV and the time period between April '91 and October '95.

3C 273 was first discovered to be an emitter of low-energy γ-rays by COMPTEL in 1991 (Hermsen et al. 1993). The source is frequently detected in individual CGRO pointings (e.g. Collmar et al. 1999),

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however, non-detections occur as well proving time variability of the MeV-flux on time scales of months (Williams et al. 1995). In time-averaged analyses 3C 273 is detected very significantly and shows in the 0.75-30 MeV band a soft spectrum, i.e. photon index $\alpha > 2$ ($E^{-\alpha}$) in combined data (Collmar et al. 1996). However, combining contemporaneous high-energy data reveals that the MeV-band is a transition region for the spectrum of 3C 273 showing a turnover from a harder ($\alpha \sim$1.7) spectrum at hard X-ray energies to a softer one ($\alpha \sim$2.5) at high-energy (>100 MeV) γ-rays (e.g. Lichti et al. 1995, von Montigny et al. 1997).

At hard (>50 keV) X-rays 3C 273 is always significantly detected by the Oriented Scintillation Spectrometer Experiment (OSSE) showing flux variations in the 50-150 keV band up to a factor of 8 during 5 years (McNaron-Brown et al. 1997). A power-law spectrum with a photon index of roughly 1.7 (Johnson et al. 1995) up to ∼1 MeV is typically observed. Above ∼1 MeV a spectral softening is found, consistent with the results of the multiwavelength campaigns. Recently, during the highest flux state as observed by OSSE, evidence for a low-energy spectral break at about 0.3 MeV was found (McNaron-Brown et al. 1997) suggesting an anticorrelation between flux and break energy.

In this paper we report on 7 weeks of continuous γ-ray observations by the EGRET and COMPTEL experiments aboard CGRO in December 1996 and January 1997. In Sect. 2 we describe the observations and the data analyses, in Sect. 3 we give the results, and discuss their implications in Sect. 4. Finally, the conclusions are presented in Sect. 5.

2. Observations and data analysis

During Cycle 6 (October 15, 1996 to November 11, 1997) of its mission, CGRO was pointed continuously to the Virgo sky region for 7 weeks, beginning on December 10, 1996 and ending on January 28, 1997. The main target was the blazar 3C 279 which is located at $(\alpha, \delta)_{2000}$ = ($12^h56^m11^s$, -5.8°47'21.5"), at a distance of ∼10.5° from 3C 273. The relevant observational parameters are given in Table 1.

The spark-chamber telescope EGRET covers the energy range from ∼30 MeV to ∼30 GeV. The instrument and its calibration is described in detail by Thompson et al. (1993) and Esposito et al. (1999). The analysis of the EGRET data followed the standard EGRET procedure i.e. using count and exposure maps as well as predictions of the diffuse γ-ray background (e.g. Hunter et al. 1997). The maps containing events with energies above 100 MeV were used for source detection and determination of the source position, and the ones of the 10 standard energy intervals for determination of the source spectrum by assuming a power law. The analysis applied the standard maximum-likelihood method (Mattox et al. 1996) and spatial selections (<25° off axis). Empirical flux correction were applied for energies below 70 MeV.

Table 1. Continuous CGRO observations of 3C 273 during Cycle 6. The viewing period (VP) number in CGRO-notation, the observational periods in calendar date and Truncated Julian Day (TJD), and the angular separation (Sep.) between 3C 273 and the pointing direction are given. The analysed time periods (VP-combinations) and their durations are given as well. For their explanation see text.

VP	Observation Time yy/mm/dd - yy/mm/dd	TJD	Sep. [°]
606.0	96/12/10 - 96/12/17	10427 - 10434	11.2
607.0	96/12/17 - 96/12/23	10434 - 10440	11.2
608.0	96/12/23 - 96/12/30	10440 - 10447	11.2
609.0	96/12/30 - 97/01/07	10447 - 10455	11.2
610.0	97/01/07 - 97/01/14	10455 - 10462	11.2
610.5	97/01/14 - 97/01/21	10462 - 10469	9.5
611.1	97/01/21 - 97/01/28	10469 - 10476	11.1

Periods	VPs	Obs. Time TJD	Dur. [days]
All	606-611.1	10427 - 10476	49
A	606-608	10427 - 10447	20
B	609+610	10447 - 10462	15
C	610.5+611.1	10462 - 10476	14
D	A + C		34

The imaging Compton telescope COMPTEL covers the energy band ∼0.75 to ∼30 MeV. For a detailed description of the COMPTEL instrument see Schönfelder et al. (1993). The COMPTEL data have been analysed following the COMPTEL standard maximum-likelihood analysis procedures, which for point-source analyses including background generation are described in sufficient detail by Bloemen et al. (1994) and which derive quantitative source parameters like detection significances, fluxes, and flux errors. For consistency checks maximum-entropy images (see e.g. Strong et al. 1992) have been generated as well.

The fluxes of 3C 273 were determined by simultaneously fitting further sources or source candidates which are indicated by the maps (see Fig. 1). This approach leads iteratively to simultaneous flux determinations of several sources, including the generation of a background model which takes into account the possible presence of further sources. This analysis has been carried out for the four standard COMPTEL energy bands. The flux results given in Sect. 3 have been derived with point spread functions assuming an $E^{-2.0}$ power-law shape for the sources, which is approximately the correct shape for the MeV-spectrum of 3C 273.

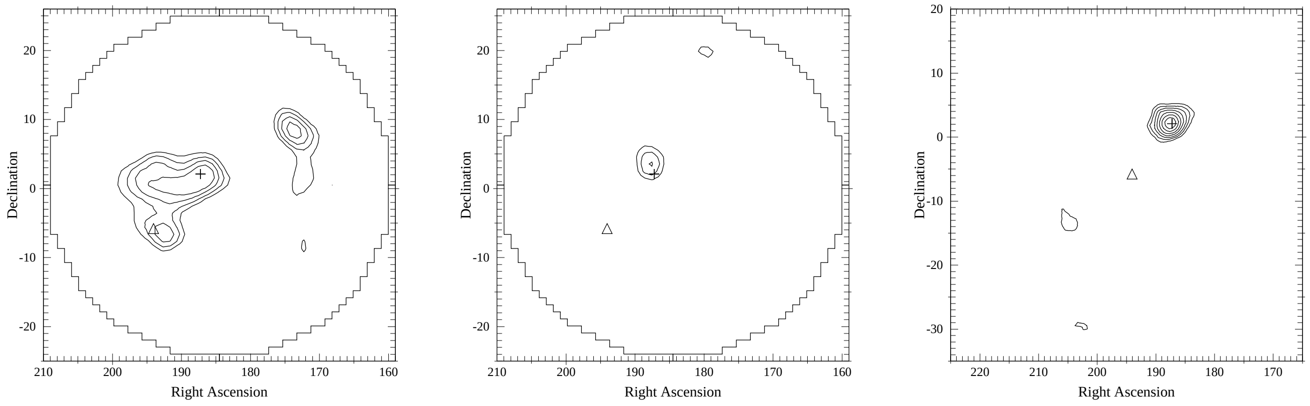

Fig. 1. Virgo maps in the γ-ray energy bands 3-10 MeV (left), 10-30 MeV (middle) as observed by COMPTEL, and >100 MeV (right) as provided by EGRET for the complete set of 7 weeks of continuous data (VPs 606 to 611.1). For COMPTEL the contour lines start at a detection significance of 3σ (χ^2_1-statistics for a known source) with a step of 0.5σ. For EGRET the contour lines also start at a detection significance of 3σ, however with a step of 1σ. The locations of the famous Virgo blazars 3C 273 (+) and 3C 279 (Δ) are indicated. 3C 273 is detected with 10.4σ by EGRET. There is significant emission from 3C 273 in both COMPTEL maps. The COMPTEL 3-10 MeV map shows hints for additional sources.

3. Results

3.1. Detections

The EGRET data analysis of the combined 7 weeks of Virgo data revealed a strong source consistent with the location of 3C 273 (Fig. 1). The overall detection significance at the position of the quasar for energies above 100 MeV is 10.4σ assuming χ^2_1-statistics for a known source. The 7-week mean flux (E>100 MeV) is $(43.4\pm5.8) \times 10^{-8}$ ph cm^{-2} sec^{-1}, which is roughly 3 times the average flux listed in the third EGRET catalogue (Hartman et al. 1999). A flux level in excess of that – $(48.3\pm11.8) \times 10^{-8}$ ph cm^{-2} sec^{-1} in VP 308.6 – had been reported previously only once (Hartman et al. 1999). 3C 273 is identified with the γ-ray source on the basis of its sky location.

Simultaneously with these EGRET findings, COMPTEL observed significant emission from the sky position of 3C 273 in three (1-3 MeV, 3-10 MeV, 10-30 MeV) out of its 4 standard energy bands. The source is not detected at the lowest COMPTEL energies (0.75-1 MeV). The overall detection significance is 7.7σ. The average flux values in the individual COMPTEL bands (see Table 2) are among the largest ever measured in this energy window, showing that the source was active in γ-rays during this period.

3.2. Time variability

To check for time variability we have subdivided the total 7 week observation into slices of the 7 individual VPs covering typically one week each (Table 1). 3C 273 was not detected by EGRET during the first two VPs (detection-significance threshold 3.5σ). It then appeared just above the detection threshold and increased further to show the

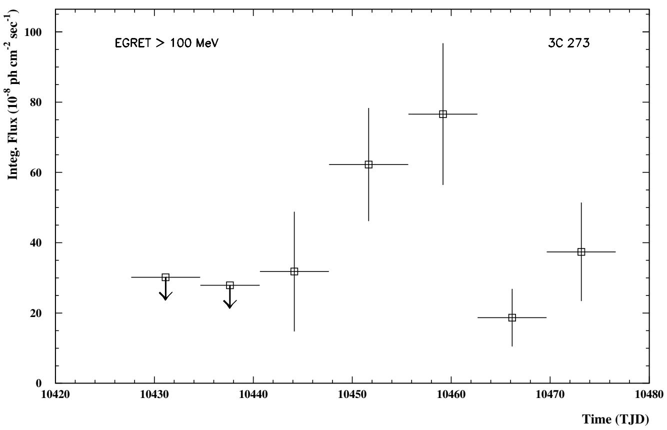

Fig. 2. The EGRET light curve of 3C 273 at energy above 100 MeV for the seven individual VPs (for the calendar dates see Table 1). The quasar was not detected during the beginning of the observations, then showed a flux increase to the highest level ever for ~2 weeks in the middle part (VPs 609 and 610), and then returned to about the previous flux level in the last two weeks. The errors are 1σ and the upper limits are 2σ.

largest γ-ray flare observed during the CGRO era. This maximum flux level of $(77\pm20) \times 10^{-8}$ ph cm^{-2} sec^{-1} is reached in VP 610. Thereafter the flux returned to an intermediate level, which is clearly detectable. Fits of the two EGRET light curves shown in Figs. 2 and 3 (upper panel) assuming a constant flux resulted in χ^2_{min}-values of 19.9 for the light curve containing 7 flux points (individual VPs) and 12.5 for the one containing 3 flux points. According to χ^2-statistics these values correspond to probabilities of 2.9×10^{-3} and 1.9×10^{-3}, respectively, for a constant flux, which convert to 3.0σ and 3.1σ evidence for a time-variable >100 MeV flux. The largest change in

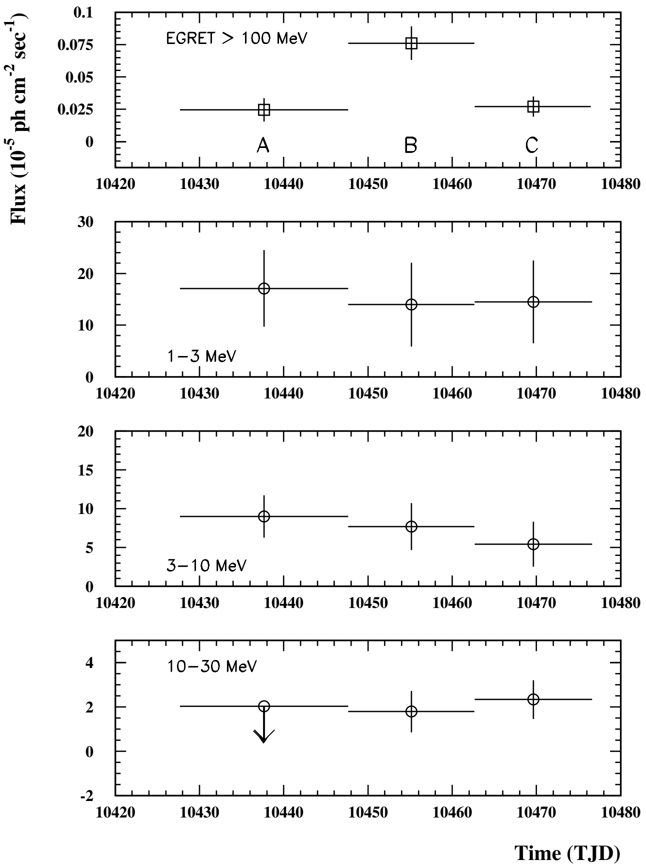

Fig. 3. EGRET (□) and COMPTEL (○) light curves of 3C 273 in different γ-ray bands. The definition of the 3 time periods (A, B, C) is given in the text. While a flare is clearly seen above 100 MeV by EGRET, no obvious flux increase is observed at energies below 30 MeV by COMPTEL. The errors are 1σ and the upper limits are 2σ.

flux occurred between VPs 610 and 610.5 when the flux dropped by a factor of $\sim$4.1 within 7 days. This is the shortest time variability at γ-ray energies ever reported for 3C 273. The significance that the two flux values are different is 2.7σ. During the two-week outburst (VPs 609 and 610) the source reached a flux level even slightly in excess to the COS-B flux reported by Swanenburg et al. (1978).

We checked for time variability in the COMPTEL bands by subdividing the data into the same time slices as chosen for EGRET. No obvious time variability is visible in either energy band, however, the statistics in the different COMPTEL bands became marginal, resulting in large error bars on the flux values. To improve the statistical significance we combined individual VPs. We defined three time intervals which were selected according to the EGRET light curve: a pre-flare period (VPs 606-608) covering 3 weeks which we shall call A in the following, a flare period (VPs 609 and 610) covering two weeks which we shall call B, and a post-flare period (VPs 610.5 and 611) which we shall call C (see also Table 1). The simultaneous

Table 2. Fluxes and upper limits for 3C 273 for the different analysed periods in units of 10^{-5}cm^{-2}s^{-1} for the COMPTEL bands and 10^{-8}cm^{-2}s^{-1} for the EGRET band. The energy bands are given in MeV. The errors are 1σ. The upper limits are 2σ. An upper limit is given when the significance of an individual flux value is less than 1σ. The errors and upper limits are statistical only. The observational periods A-D are defined in Table 1 and described in the text.

	COMPTEL				EGRET
Period	0.75-1	1-3	3-10	10-30	$\geq$100
All	<10.7	15.2±4.5	7.5±1.7	1.5±0.5	43.4±5.8
A	<17.3	17.1±7.4	9.0±2.7	<2.0	24.6±9.0
B	<23.0	14.0±8.1	7.7±3.0	1.8±0.9	76.1±12.9
C	<18.8	14.5±8.0	5.4±2.9	2.3±0.9	27.1±7.7
D	<12.8	15.8±5.4	7.4±2.0	1.4±0.6	27.7±6.0

EGRET and COMPTEL 3C 273 fluxes for different energy bands and various time periods are listed in Table 2 and are plotted in Fig. 3. In contrast to EGRET, COMPTEL observes no obvious time variability. The same χ^2-procedure as applied to the EGRET data showed that the different COMPTEL flux values are consistent with a constant level as is also obvious from Fig. 3. In particular the COMPTEL light curves do not show a hint of increased γ-ray emission during the EGRET flaring period. This result suggests that the observed flare is either solely a high-energy (>30 MeV) phenomenon, or a time offset of at least 2 weeks between the EGRET and COMPTEL γ-ray bands is required.

3.3. Energy spectra

The EGRET spectral analysis followed the standard EGRET procedure (see Sect. 2). The energy range between 30 MeV and 10 GeV was subdivided into 10 energy intervals and the likelihood analysis was used to estimate the number of source photons in each energy bin. The data were fit to a single power-law model of the following form

$$I(E) = I_0 (E/E_0)^{-\alpha} \text{ photons cm}^{-2}\text{s}^{-1}\text{MeV}^{-1} \quad (1)$$

with the parameters α (photon spectral index) and I_0 (intensity at the normalization energy E_0). E_0 was chosen such, that the two free parameters are minimally correlated. We derived 1σ-errors on the parameters by adding 1.0 to the minimum χ^2-value (Mattox et al. 1996).

This approach was applied to the sum of all data as well as to selected subsets (see Fig. 3, Table 1) to check for a possible trend in time. In addition we summed the subsets A and C having roughly equal flux levels, which we shall call D, to check for a possible spectral trend with flux by using the improved event statistics. The results of the spectral fitting are given in Table 3. First of all the spectra are well fitted by simple power-law functions:

the average spectral index in the EGRET band is $\alpha = 2.40\pm0.14$, which is comparable to previous results. For instance, von Montigny et al. (1997) found spectral indices in the range between 2.2 and 3.2 with a trend of spectral hardening with increased source flux. The EGRET fits show this trend as well: the spectrum is hardest during the flaring period. However, this is not significant because the error on the spectral slope is quite large.

To derive the COMPTEL fluxes of 3C 273, we have applied the standard maximum-likelihood method as described in Sect. 2. Background-subtracted and deconvolved source fluxes in the 4 standard energy bands have been derived by taking into account the presence of further γ-ray sources (3C 279 at α/δ = 194.1°/-5.8°, 4C -02.55 (1229-021) at α/δ = 188.0°/-2.4°) and source candidates (at α/δ = 193.5°/0.5°and α/δ = 173.5°/8.5°), showing some evidence in the maps (Fig. 1). We note that inclusion of these further sources and source candidates has only a marginal effect on the flux of 3C 273. Their inclusion or exclusion changes the derived 3C 273 fluxes only within its error bars. Assuming a power-law shape, the quasar is fitted typically with a spectral index of ∼2 throughout the COMPTEL energy band. For example, the sum of all data ('ALL') which has the best statistics, yields $\alpha = 1.92\pm0.13$ between 0.75 and 30 MeV, which is significantly harder than $\alpha = 2.41\pm0.14$ as found in the EGRET range for the same observational period (Fig. 4). This result indicates a spectral hardening towards lower energies with the turnover starting at a few MeV. This spectral behaviour of 3C 273 is well known and has been reported previously (e.g. Lichti et al. 1995, von Montigny et al. 1997).

To take advantage of the contemporaneous observations of both instruments in neighbouring energy regimes, we combined the deconvolved EGRET and COMPTEL spectra for the different time periods. Fitting the whole energy range (0.75 MeV to 10 GeV) with a power-law model, we derive harder spectral slopes and increased χ^2_{red}-values compared to fitting solely the EGRET range. This effect weakens if we exclude the lowest-energy (0.75-1 MeV) spectral point, and disappears when we subsequently remove the next (1-3 MeV) COMPTEL flux point from the fitting procedure. This behaviour is easily explained by the spectral turnover at low energies, which seems to affect the fits only below 3 MeV. Fitting a broken power-law model

$$I(E) = \begin{cases} I_0(E/E_0)^{-\alpha_2} & \text{if } E > E_b \\ I_0(E_b/E_0)^{-\alpha_2}\,(E/E_b)^{(\Delta\alpha-\alpha_2)} & \text{if } E < E_b \end{cases} \quad (2)$$

where I_0 describes the differential source flux at the normalization energy E_0, α_2 the high-energy spectral photon index, $\Delta\alpha$ the break in spectral photon index towards lower energies ($\Delta\alpha = \alpha_2$ - α_1), and E_b the break energy, provides consistent results. The best-fit value for the break energy for the sum of all data is found to be at ∼5 MeV, which, however, is not well defined due to the small lever-arm towards lower energies. Considering these facts, we

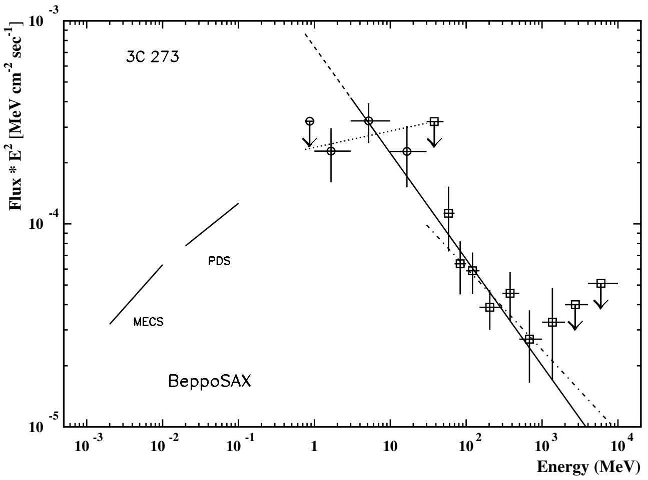

Fig. 4. Quasi-simultaneous BeppoSAX-CGRO high-energy spectrum of 3C 273 in an $E^2\times$ differential-flux representation. The EGRET (□) and COMPTEL (∘) spectral points are derived from the sum of the whole observation (7 weeks). The errors are 1σ and the upper limits are 2σ. An upper limit is drawn when the significance of an individual flux value is less than 1σ. The solid line represents the best-fit power-law model for the range 3 MeV to 10 GeV. The dashed lines show the extrapolation towards lower energies. The dotted line represents the best-fit power-law model for only the COMPTEL data (0.75-30 MeV) and the dashed-dotted line the one for solely the EGRET data (30 MeV - 10 GeV). The BeppoSAX power-law shapes were observed on January 13, 1999 (Haardt et al. 1998), located within the CGRO observational period. The strong spectral turnover at a few MeV is evident.

conclude, that the EGRET power-law spectrum extends into the COMPTEL band down to ∼3 MeV before it is substantially altered by the spectral turnover. This is illustrated in Fig. 4. By chance the quasar was observed simultaneously in the X-ray band by the BeppoSax satellite. Haardt et al. (1998) published the X-ray results, i.e. fluxes and spectra, of 3C 273 covering a monitoring period of 4 days (January 13, 15, 17, and 22, 1997). These X-ray observations are coincident in time with the transition from the γ-ray flaring period to the moderate post-flare γ-ray level (Fig. 2). Fig. 4 shows a broad-band high-energy spectrum of 3C 273, containing the COMPTEL and EGRET spectra for the sum of all 7 weeks and the best-fit power-law shape for the quasi-simultaneous X-ray measurements (covering only one day) provided by Haardt et al. (1998).

To investigate this high-energy component in more detail, we fitted the different observational subsets between 3 MeV and 10 GeV with single power-law models (Fig. 5). We take advantage of this enlarged (with respect to only EGRET) energy band, for which the spectral index can be determined more accurately. So, for the 3 MeV to 10 GeV band, the trend that during the flare the spectrum hardens as suggested by the EGRET analysis (see above), is observed more significantly. Especially if we compare the periods B and D. The 1σ statistical errors in spectral in-

Table 3. Results of the power-law fitting ($I(E) = I_0\ (E/E_0)^{-\alpha}$) for the different time periods. The left part gives the results for fitting only the EGRET data (30 MeV - 10 GeV), while the right part shows the results of fitting the combined EGRET and COMPTEL (3 MeV - 10 GeV). The errors on the fit parameters are derived by the χ^2_{min}+1 contour level.

	EGRET (30 MeV-10 GeV)				COMPTEL + EGRET (3 MeV-10 GeV)			
Obs. Period	PL-Index (α)	$I_0 \times 10^{-9}$ [ph/(cm^2 s MeV)]	E_0 [MeV]	χ^2_{red}	PL-Index (α)	$I_0 \times 10^{-9}$ [ph/(cm^2 s MeV)]	E_0 [MeV]	χ^2_{red}
All	2.41±0.14	1.18±0.13	197.93	0.42	2.52±0.07	6.69±0.67	100	0.45
A	2.65±0.47	1.57±0.46	150.35	0.36	2.70±0.14	4.56±1.27	100	0.36
B	2.41±0.21	2.56±0.38	176.16	0.62	2.42±0.10	10.10±1.36	100	0.52
C	2.52±0.32	1.04±0.25	175.65	0.41	2.60±0.13	4.70±1.04	100	0.61
D	2.61±0.27	1.30±0.24	160.65	0.60	2.66±0.10	4.67±0.75	100	0.52

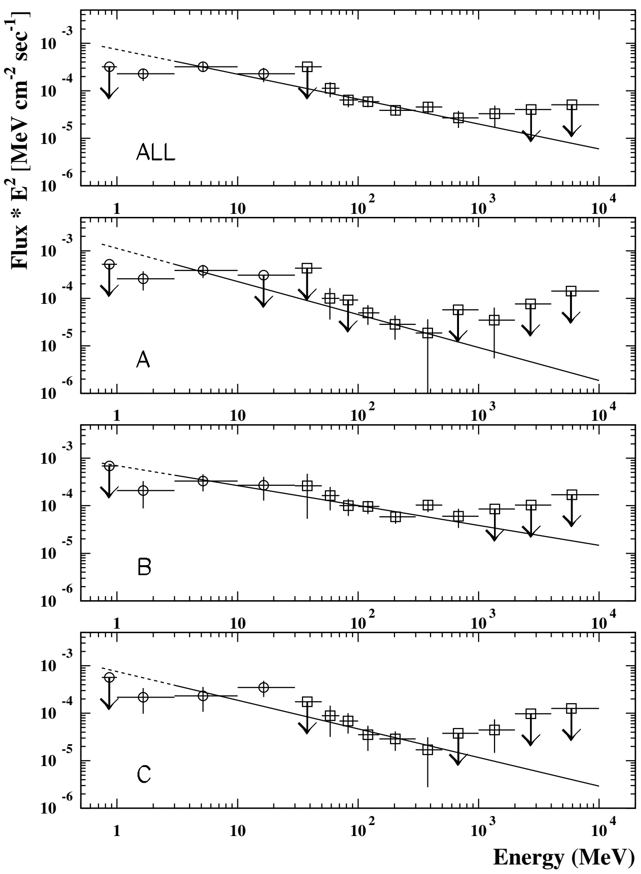

Fig. 5. Combined EGRET (□) and COMPTEL (○) energy spectra for different time periods in an $E^2\times$ differential-flux representation. The errors are 1σ and the upper limits are 2σ. An upper limit is drawn when the significance of an individual flux value is less than 1σ. The solid line represents the best-fit power-law model for the range 3 MeV to 10 GeV. The dashed lines show the extrapolation towards lower energies.

dex during the flare and non-flare intervals do not overlap anymore. The fit results for the EGRET band only and this enlarged band are given in Table 3, and the latter ones are shown graphically in the Figs. 5 and 6. Along the 7-week observation, 3C 273 is observed to have a steep spectrum at the beginning, which hardens during the two-week flaring period, and turns back to roughly the same shape in the 2 week post flare period (Fig. 7). This result is consistent with the constant flux observed at COMPTEL energies. The flare occurs mainly at energies above 100 MeV, not affecting the COMPTEL points which results in a hardening of the overall γ-ray spectrum.

From this spectral analysis, we conclude too, that we either observed a phenomenon which occurs solely at high γ-ray energies, or that there are time delays between the different γ-ray bands. The first case would require an additional spectral component triggered by some mechanism which is only effective at EGRET energies. The second possibility would require that the COMPTEL energies are either delayed by two weeks or would be in advance by three weeks with respect to EGRET.

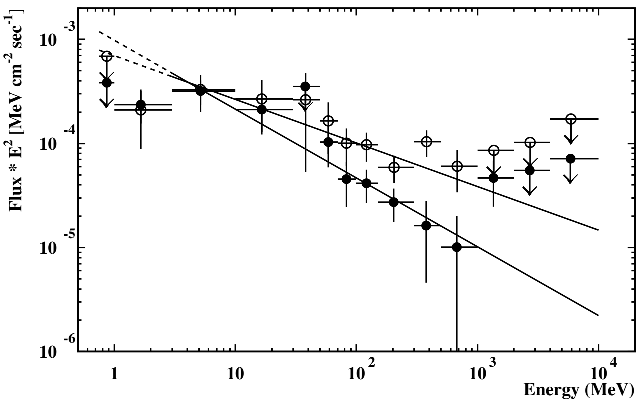

Fig. 6. The spectra of the flare state (B, open circles) and the sum of the lower flux levels (A+C, filled circles) are compared. The two spectra differ mainly above 100 MeV.

4. Discussion

At the end of 1996 and early 1997 the CGRO experiments EGRET and COMPTEL observed the well-known quasar 3C 273 at γ-ray energies continuously for 7 weeks. The

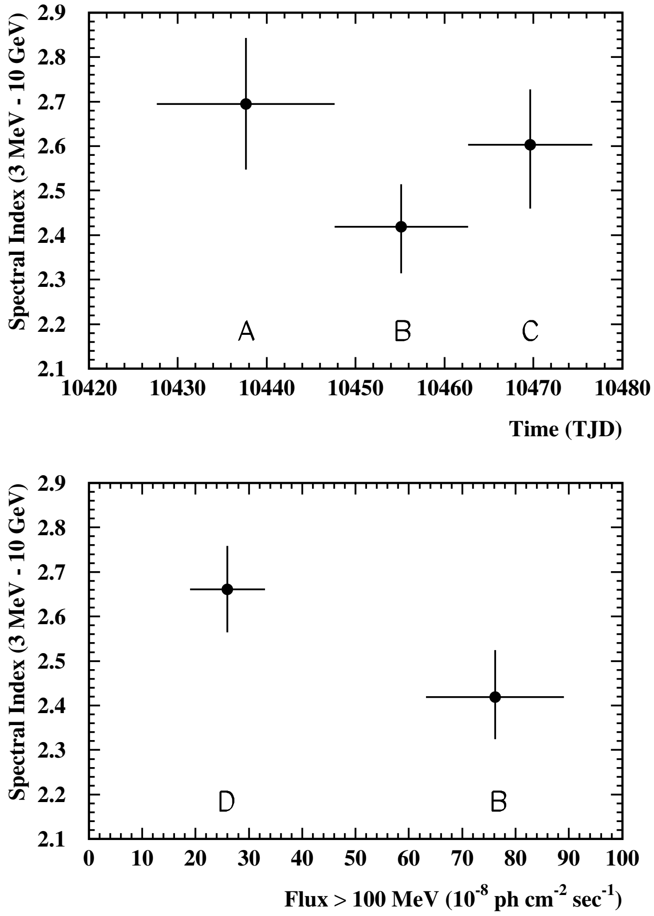

Fig. 7. The spectral index (3 MeV - 10 GeV) as a function of time (periods A, B, and C) is shown in the upper panel and of source flux >100 MeV (periods B and D (A+C)) in the lower panel. The errors are 1σ. There is evidence for spectral hardening with increasing flux.

blazar was γ-ray active and therefore it was significantly detected by both experiments. Assuming isotropic emission, H_0=60 km/s/Mpc, and a q_0=0.5 cosmology, we derive an average 7-week luminosity in the EGRET band (100 MeV - 10 GeV) of $\sim 1.7\times10^{46}$erg/s, for the flaring period (period B in Table 2) $\sim 2.7\times10^{46}$erg/s, and $\sim 0.9\times10^{46}$erg/s for the periods outside the two-week flare. The 7-week average luminosity in the COMPTEL band (1-30 MeV) is derived to be $\sim 12\times10^{46}$erg/s.

The blazar was simultaneously observed in the X-ray band by the BeppoSax satellite in a monitoring fashion covering a period of 1.5 weeks with four individual pointings. In X-rays the quasar was about 15% brighter in the first observation than in the last one (Haardt et al. 1998), which is consistent with the γ-ray behaviour above 100 MeV. In addition, they note that during these monitoring observations the source was, on average, a factor of 2 brighter as observed half a year earlier. This suggests a correlation of X- and γ-ray behaviour of 3C 273.

Simultaneous X-ray and γ-ray measurements provide the possibility of estimating some physical source parameters, if one assumes that both photon populations are generated co-spatially. This is not an unreasonable assumption, given the indication of correlated variability as mentioned above. It was observed also in other blazars like 3C 279 for example (Wehrle et al. 1998). Using the simultaneous X-ray spectra of the BeppoSax Medium Energy Concentrator Spectrometers (MECS) published by Haardt et al. (1998) we derive a flux of $\sim 16\mu$Jy at 1 keV for 3C 273. Applying the expression for the lower limit on the Doppler factor, δ, given by Dondi & Ghisellini (1995) and assuming H_0=60 km/s/Mpc, we derive

$$\delta \geq \left(684\, t_{var}^{-1}\, E_{\gamma}^{\alpha}\right)^{\frac{2}{(4+2\alpha)}}, \qquad (3)$$

where t_{var} is the variability time scale in days, E_{γ} the highest unabsorbed γ-ray energy in GeV, and α the spectral index in X-rays. With a variability scale of one week as observed by EGRET at a significance level of 2.7σ, an E_{γ} of 1 GeV, and an α of 0.6 (energy index) as observed simultaneously by the BeppoSax MECS, we derive a lower limit on the Doppler factor of

$$\delta \geq 2.4. \qquad (4)$$

A $\delta \geq 2.4$ implies that the γ-ray luminosities mentioned above overestimates the intrinsic luminosities at least by a factor of about 33 since $L_{obs} = \delta^{3+\alpha} L_{intr}$.

Although EGRET observed time variability at energies above 100 MeV, the COMPTEL experiment between 1 and 30 MeV simultaneously measures a constant flux of 3C 273. In particular, COMPTEL observes no hints of increased γ-ray emission in any of its energy bands during the two-week flaring period. This is a surprising result, and in some respects different to simultaneous COMPTEL/EGRET observations of other flaring blazars. For example, during the major outburst of 3C 279, the COMPTEL 10-30 MeV flux followed the flux trend as observed by EGRET at higher energies (Collmar et al. 1997a). Also, by analysing the COMPTEL data of the first 3.5 years on the blazar PKS 0528+134, Collmar et al. (1997b) found the trend that the COMPTEL upper energy band follows the EGRET light curve, while the emission in the COMPTEL 1-3 MeV band was independent of the EGRET-observed behaviour. According to the measurements presented here, the largest γ-ray flux (>100 MeV) of 3C 273 is only a high-energy phenomenon, because it is (at least simultaneously) restricted to energies above $\sim$30 MeV. This is consistent with the hardening of the γ-ray spectrum during the flare. This observation suggests either an additional spectral component which becomes important at energies above 100 MeV or a time-offset between the high- and low-energy γ-rays is required.

A different behaviour in the MeV- and >100 MeV band had been observed in the so-called 'MeV-blazars' GRO J0506-609 (Bloemen et al. 1995) and PKS 0208-512

(Blom et al. 1995), which - in contrast to the presented case - showed simultaneously strong MeV-emission compared to weak emission above 100 MeV. These sources indicated first that several emission components or mechanisms can be operating at γ-ray energies.

In the standard models, the γ-ray emission is generated within a jet, where blobs, filled with relativistic leptons, are moving at relativistic speeds along the jet axis. The γ-ray emission is generated by inverse-Compton interactions of these blob leptons with soft photons which either are provided by the environment (e.g. accretion disk) of the jet or are self-generated synchrotron photons. In such a picture, the observed behaviour of 3C 273 could be qualitatively explained by a change in the energy distribution of the blob leptons, by a change of the energy distribution of the soft target photons or by both. If the γ-ray flare is triggered by a change in the energy distribution of the blob leptons, the observation would require that only the high-energy end of the distribution, responsible for the γ-rays in the EGRET band, is increased in energy as well as in number density, while at lower energies the distribution has to remain constant to keep the MeV-emission unchanged. This case, if applicable, might provide hints on the particle acceleration mechanism. If a variation of the soft photon distribution is responsible for the γ-ray flare, a flare in a certain wavelength band, e.g. UV flare of accretion disk photons, could trigger the event.

An apparently natural explanation of this uncorrelated EGRET-COMPTEL behaviour would be if the MeV- and >100 MeV-emissions emanate from spatially different regions. However, we consider this explanation unlikely because – as mentioned above – simultaneous γ-ray variations have been observed by EGRET and COMPTEL in several blazars. Also during the observational period presented here, both experiments found 3C 273 in an active γ-ray state, which suggests a common region of photon generation.

In our opinition the most plausible scenario appears to be that the MeV and the GeV emissions are dominated by different radiation mechanisms with different flaring amplitudes, but emitted co-spatially by the same population of relativistic electrons which are also responsible at least for the high-frequency part of the synchrotron component. Such a two-component scenario for spectral variability during high-energy flares has first been suggested for PKS 0528+134 by Collmar et al. (1997b); see also Böttcher & Collmar (1998) and Mukherjee et al. (1999). Given typical parameter values for the relativistic electron distribution in AGN jets, and scaling δ in units of 3 (due to the results of Eq. 4), the synchrotron emission peaks at

$$\langle\epsilon\rangle_{Sy} \sim 7 \cdot 10^{-8} B_0 \langle\gamma\rangle_3^2 \left(\frac{\delta}{3}\right), \tag{5}$$

where $\epsilon = h\nu/(m_e c^2)$ is the dimensionless photon energy, B_0 is the co-moving magnetic field in Gauss, and $\langle\gamma\rangle_3$ is the average Lorentz factor of the electrons in units of 10^3. With B_0 and $\langle\gamma\rangle_3$ being of order unity, the synchrotron peak is at $\nu_{sy} \sim 10^{13}$ Hz, as generally observed for 3C 273. We will discuss two possible radiation mechanisms for the observed high-energy flare: a) Comptonization of accretion disk radiation which is reprocessed by broad-line region clouds (ECC for External Comptonization of radiation from Clouds; Sikora et al. 1994), and b) Comptonization of synchrotron radiation from the jet, reprocessed by broad-line region clouds (RSy for synchrotron reflection) as proposed by Ghisellini & Madau (1996). The ECC spectrum, which assumes the accretion disk ('blue bump') photons to be the soft target photons, is expected to have a rather narrow spectral distribution, peaking around

$$\langle\epsilon\rangle_{ECC} \sim 3 \cdot 10^3 \langle\epsilon_D\rangle_{-4} \Gamma_{10} \langle\gamma\rangle_3^2 \left(\frac{\delta}{3}\right), \tag{6}$$

where $\langle\epsilon_D\rangle_{-4}$ ($\equiv \langle\epsilon_D\rangle/10^{-4}$) – being of order unity – is the dimensionless νF_ν peak energy of the accretion disk spectrum and Γ_{10} is the bulk Lorentz factor in units of 10, which is also assumed to be of order unity. Consequently, this peak is expected to be at ~ 1 GeV. In contrast, the RSy spectrum is expected to be much broader (similar to the synchrotron self-Compton spectrum) and peaks around

$$\langle\epsilon\rangle_{RSy} \sim 7 B_0 \langle\gamma\rangle_3^4 \Gamma_{10}^2 \left(\frac{\delta}{3}\right), \tag{7}$$

typically at MeV energies. The factors Γ_{10} and Γ_{10}^2 in Eqs. (6) and (7) arise from the Lorentz boost of the external radiation field into the comoving rest frame of the blob and of the jet synchrotron radiation into the stationary frame of the BLR.

The estimates derived from Eqs. (6) and (7) indicate that a flare in the EGRET energy range without a significant variation of the MeV emission is more likely to be caused by the ECC mechanism than by the RSy scenario. We point out that these interpretations are based on time-variability of EGRET which is signifcant at 3.1σ.

Recently McHardy et al. (1999) reported simultaneous mm, infrared (IR), and X-ray (3-20 keV) observations of 3C 273 which cover in part the same time period as the γ-ray observations reported here. In particular they observed a simultaneous IR and X-ray flare lasting for about 10 days, which in fact is simultaneous to the high-energy γ-ray flare observed by EGRET. These simultaneous flares add important information in light of the two-component hypothesis for the γ-ray spectrum proposed here and provide additional constraints for the modelling of the emission processes in this quasar. A discussion and interpretation of the peculiar variability pattern of 3C 273 in IR, X-rays and γ-rays as observed in early 1997 will be given by Böttcher & Collmar (2000).

5. Conclusion

From December 10, 1996 to January 28, 1997 the CGRO instruments EGRET and COMPTEL observed the Virgo sky region continuously for 7 weeks, detecting 3C 273 in an active γ-ray state. EGRET (>100 MeV) observed a time-variable flux, peaking during a 2-week flaring period at its highest level observed during the CGRO-era. COMPTEL, however, does not observe any contemporaneous γ-ray flare at energies below $\sim$30 MeV, showing that this outburst is restricted to γ-ray energies above 30 MeV. This is consistent with the spectral hardening observed in the 3 MeV to 10 GeV energy band during the flaring period.

The peculiar variability properties of the flare may be explained in terms of a two-component spectral model with the emission in the EGRET energy range produced by Comptonization of reprocessed accretion disk emission. The different variability behaviour in γ-rays is inconsistent with the synchrotron-reflection model being the cause of the γ-ray flare.

This observation covers an opportune sequence of low pre-flare, high flare, and again low post-flare emission in γ-rays. In general, this γ-ray observation could turn out to be important for further modelling of blazar emission processes because it is well located in time and therefore can possibly be correlated to flux measurements of monitoring observations in other wavelength regions.

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