A Large Gamma-Ray Flare from the Blazar 3C 273

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I) Introduction

The quasar 3C 273 is a 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 with the trend of spectral hardening with increasing intensity. The second EGRET source catalog (Thompson et al. 1995) lists 3C 273 with an average flux value of $(16.0\pm2.6) \times 10^{-8}$ *ph cm*$^{-2}$ *s*$^{-1}$.

3C 273 was 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, however, non-detections occur as well proving time variability of the MeV-flux on time scales of months. In time-averaged analyses 3C 273 is detected very significantly, in fact it is the brightest extragalactic point source for COMPTEL (Collmar et al. 1996). In the COMPTEL 0.75-30 MeV band, 3C 273 shows a soft spectrum ($\alpha > 2$) in combined data. 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).

II) Observation and Data Analysis

During Cycle 6 (October 15, 1996 to November 11, 1997) of its mission, CGRO was pointed continously to the Virgo sky region for seven weeks, beginning on December 12, 1996 and ending on January 28, 1997. The main target was the blazar 3C 279 which is located at (α, δ) = (194.1, -5.8), 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 analysis of the EGRET data followed the standard EGRET procedure. The imaging Compton telescope COMPTEL covers the energy range between ∼0.75 MeV and ∼30 MeV and the analysis of its data followed the COMPTEL standard analysis procedures.

Table 1. Continuous CGRO observations of 3C 273 during Cycle 6. The viewing period (VP) number in CGRO-notation, the observational periods and duration, and the angular separation between 3C 273 and the pointing direction are given.

VP	Obs. Time yy/mm/dd - yy/mm/dd	Dur. [days]	Ang. Sep. °
606.0	96/12/10 - 96/12/17	7	11.2
607.0	96/12/17 - 96/12/23	6	11.2
608.0	96/12/23 - 96/12/30	7	11.2
609.0	96/12/30 - 97/01/07	8	11.2
610.0	97/01/07 - 97/01/14	7	11.2
610.5	97/01/14 - 97/01/21	7	9.5
611.1	97/01/21 - 97/01/28	7	11.1

III) Results

III.1 Detections

In the sum of all data EGRET detects 3C 273 with a significance of 100 MeV is 10.4σ at energies above 100 MeV (Fig. 1). The average flux (E>100 MeV) is $(43.4\pm5.8) \times 10^{-8}$ ph cm^{-2} sec^{-1}, which is about 2.7 times the average flux listed in the 2nd EGRET catalog (Thompson et al. 1995) and is the second largest observed by EGRET. 3C 273 is identified with the γ-ray source on the basis of its sky location.
COMPTEL observed simultaneously significant emission from 3C 273 in three (1-3 MeV, 3-10 MeV, 10-30 MeV) out of its 4 standard energy bands (Fig. 1). The overall detection significance is 7.7 σ. The average flux values in the individual COMPTEL bands are among the largest ever measured at these energies.

III.2 Time Variability

To check for time variability we analysed the 7 VPs, which cover typically one week each (Table 1), individually. The EGRET light curve is shown in Fig. 2. The maximum flux level of $(77\pm20) \times 10^{-8}$ ph cm^{-2} sec^{-1} is reached in VP 610.
No obvious time variability is visible in either COMPTEL band analysing the individual VPs, however, the statistics in the different COMPTEL bands became marginal. To increase photon statistics we combined individual VPs by defining 3 time intervals which were selected according to the EGRET light curve: a pre-flare period (VPs 606-608) which we call **A**, a flare period (VPs 609 and 610) which we call **B**, and a post-flare period (VPs 610.5 and 611) which we call **C** (see Fig. 2). The EGRET and COMPTEL light curves for these periods are shown in Fig. 2. In contrast to EGRET, COMPTEL observes no 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.

III.3 Energy Spectra

The EGRET spectra (30 MeV - 10 GeV) for the different time periods were fitted with a power-law (PL) model. The average spectral index in the EGRET band is α = 2.40±0.14, which is comparable to previous results. There is a trend, however not significant, of spectral hardening with increasing source intensity. A power-law fit to the sum of all COMPTEL data yields α = 1.90±0.16 between 0.75 and 30 MeV, which is significantly harder than found in the EGRET range. This result indicates the well-known spectral hardening towards lower energies with the turnover starting at a few MeV. To take advantage of the continous parallel observations of both instruments by avoiding the spectral turnover at lower energies, we fitted the different observational subsets between 3 MeV and 10 GeV with a PL-model. The results are given in Table 2 and are shown graphically in Figure 3. Along the 7-week observation, 3C 273 is observed to have a steep spectrum at the beginning (period A), which significantly - due to the enlarged energy range the PL-index is determined more accurately - hardens during the two-week flaring period (B), and returned to roughly the previous shape in the post flare period (C). This result is consistent with the constant flux observed at COMPTEL energies. The flare occured mainly at energies above 100 MeV, which resulted in a spectral hardening and which is consistent with its absence at COMPTEL energies.

Table 2. Results of the PL-fitting of the combined EGRET and COMPTEL (3 MeV - 10 GeV) data for the different time periods. The errors on the fit parameters are derived by the χ^2_{min}+1 contour level.

Obs. Period	PL-Index (α)	$I_0 \times 10^{-9}$ [ph/(cm^2 s MeV)]	E_0 [MeV]	χ^2_{red}
All	2.52±0.07	6.69±0.67	100	0.45
A	2.70±0.14	4.56±1.27	100	0.36
B	2.42±0.10	10.10±1.36	100	0.52
C	2.60±0.13	4.70±1.04	100	0.61
D	2.66±0.10	4.67±0.75	100	0.52

IV) Summary

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 its highest flux level ever observed during the CGRO-era. COMPTEL, however, does not observe obvious time variability at energies below ∼30 MeV. 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 the spectral analysis for different time periods, we found evidence for a spectral hardening during the flaring period, which is consistent with the flare occuring mainly at the higher energies and with its absence at COMPTEL energies of a few MeV.
From these results we conclude, that we either observed a phenomenon which occured solely at high energies, or that there are time delays between the different energy bands. The first possibility would require an additional spectral component which is only effective at EGRET energies and the second one that the COMPTEL energies are offset in time by 2 weeks with respect to EGRET.

Figures

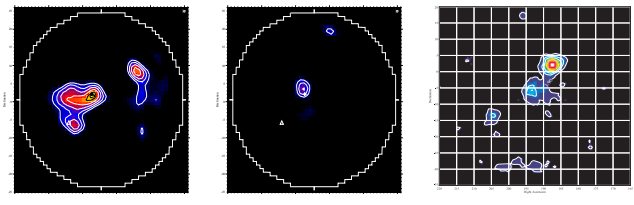

Figure 1. Virgo significance maps in the γ-ray energy bands 3-10 MeV (left), 10-30 MeV (middle) as observed by COMPTEL, and >100 MeV (right) as provided by EGRET for the complete set of 7 weeks of continuos data (VPs 606 to 611.1). For COMPTEL the contour lines start at a detection significance of 3σ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

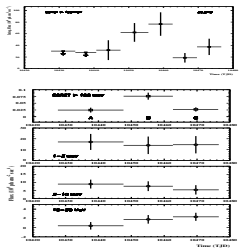

Figure 2. Light-curves of 3C 273 for different γ-ray energy bands. The upper panel shows the EGRET fluxes (>100 MeV) during individual VPs. The lower panels show the EGRET and COMPTEL light curves for the periods A, B, and C (see text). While the flare is clearly seen above 100 MeV, no obvious flux increase is observed at lower energies by COMPTEL. The errors are 1σ and the upper limits are 2σ.

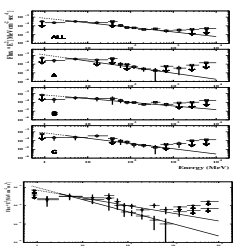

Figure 3. Combined EGRET (squares) and COMPTEL (circles) energy spectra for different time periods. The solid lines represent the best-fit power-law models for the range 3 MeV to 10 GeV. The dashed lines show the extrapolation towards lower energies. The lower panel shows the spectra of the flare state (B, ○) and the sum of the lower flux levels (A+C, ●). The two spectra differ mainly above 100 MeV. The errors are 1σ and the upper limits are 2σ.