

# COMPTEL GAMMA-RAY OBSERVATIONS OF THE QUASARS CTA 102 AND 3C 454.3

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## ABSTRACT

The blazar-type active galactic nuclei (AGNs) CTA 102 (QSO 2230+114) and 3C 454.3 (QSO 2251+158), located about  $7^\circ$  apart on the sky, were observed by the Compton Gamma Ray Observatory at four epochs in 1992. Both were detected by *EGRET* and here we present the *COMPTEL* observations of the two quasars. These observations clearly indicate that the power-law spectra measured by *EGRET* above  $\sim 50$  MeV show a flattening at lower MeV energies. A comparison with observations at other wavelengths shows that the power spectra of CTA 102 and 3C 454.3 peak at MeV energies. This behaviour appears to be a common feature of AGNs radiating at gamma-ray energies.

## INTRODUCTION

An increasing number of active galactic nuclei (AGNs) is being detected by the *COMPTEL* telescope on the Compton Gamma Ray Observatory (CGRO), which explores the gamma-ray sky at energies between about 0.75 and 30 MeV. *COMPTEL* has found the soft gamma-ray counterparts of the quasars 3C 279, 3C 273 (Hermsen et al. 1993), PKS 0528+134 (Collmar et al. 1993), and the radio-galaxy Cen A (Steinle et al. 1992). Here we present observations of the quasars CTA 102 (QSO 2230+114) and 3C 454.3 (QSO 2251+158), which are separated on the sky by about  $7^\circ$ . A detailed description of the findings is given by Blom et al. (1993).

Except for Cen A, all these AGNs have been detected by the *EGRET* telescope aboard CGRO (Fichtel et al. 1993), which observes the gamma-ray sky at higher energies (30 MeV–30 GeV). *EGRET* has already found  $\sim 30$  AGNs, of which some are good candidates for study by *COMPTEL* considering the extrapolated spectra measured by *EGRET* and the sensitivity limits of *COMPTEL*.

The majority of AGNs observed at gamma-ray energies share a number of characteristics which classify them as blazars. They are all compact, radio loud, flat-spectrum radio sources ( $\alpha < 0.5$  between 2.7 and 5 GHz, with flux density  $S \sim \nu^{-\alpha}$ ), often showing superluminal motion and high optical polarisation. Some are BL Lac objects, others are optically violent variable (OVV) quasars. The quasars CTA 102 and 3C 454.3 exhibit these blazar properties.

The *COMPTEL* observations of 3C 273, 3C 279 and PKS 0528+134 indicate a spectral break at MeV energies compared to the extrapolated power-law spectra measured by *EGRET*.

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The observations of CTA 102 and 3C 454.3 show the same behaviour, as is illustrated below. This suggests that these breaks may be a common feature of blazars. All *COMPTEL* blazars appear to show superluminal motion, with the possible exception of PKS 0528+134 (which shows only an asymmetrical core). Gamma-ray AGNs appear to be variable on the time scale of months, sometimes down to days.

## INSTRUMENT AND ANALYSIS TECHNIQUES

*COMPTEL* has the ability to detect gamma-ray photons in the energy range between 0.75 MeV and 30 MeV with an energy resolution better than 10% FWHM. With its field-of-view (FOV) of 1 steradian, *COMPTEL* images a large part of the gamma-ray sky with a location accuracy of typically  $1^\circ$ . Each incident photon detected by *COMPTEL* is first Compton scattered in an upper layer of detectors and then absorbed in a lower layer (see Schönfelder *et al.* 1993 for a complete description of the instrument). The response of the instrument is known from pre-launch calibrations and simulations. We adopted an  $E^{-2}$  input spectrum for the determination of the instrument response. Our findings are not sensitive to this specific choice.

Skymaps are generated by either applying a maximum-likelihood method (de Boer *et al.* 1992) or a maximum-entropy deconvolution method (Strong *et al.* 1992). From the first method the flux and the statistical significance of the sources can be determined directly. The maximum-entropy analysis yields a photon intensity image from which a source flux can also be calculated. Both methods have been found to give consistent results. All results presented here were obtained with the maximum-likelihood technique.

Typically, more than 95% of the number of  $\gamma$ -rays in a 3-D *COMPTEL* data space can be attributed to the background (instrumental and isotropic). The likelihood analysis in particular requires a careful estimate of this background, for which a variety of methods has been studied. The background model used in the present work is determined by applying a filter technique to the 3-D dataspace, which smooths the photon distribution and eliminates source signatures in first-order approximation. The likelihood algorithms use a modified instrument response to take this filtering into account. For a description of this method see Bloemen *et al.* (1993).

## OBSERVATIONS AND RESULTS

The quasars CTA 102 and 3C 454.3 were in the FOV of *COMPTEL* during four different observation periods of the all-sky survey performed in the first year of the mission (see Table 1). During observation period 19, *EGRET* detected CTA 102 (Nolan *et al.* 1993) and 3C 454.3 (Hartman *et al.* 1993) at gamma-ray energies above 40 MeV. We divided the energy range covered by *COMPTEL* into four energy bands (0.75–1, 1–3, 3–10, and 10–30 MeV) and generated maximum-likelihood maps for each observation period. We combined observations 26 and 28, because observation 26 was very short.

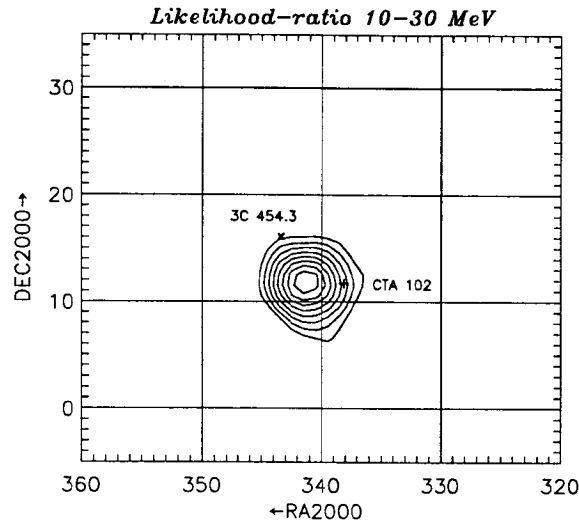


Figure 1: Likelihood-ratio map (10–30 MeV) derived from a combination of all four *COMPTEL* observations of CTA 102 and 3C 454.3 listed in Table 1. The contour levels start at  $-2 \ln \lambda = 9$ , with step of 3. See text for details.

For energies below 10 MeV, none of the maps provides convincing evidence for the detection of CTA 102 or 3C 454.3. For the 10–30 MeV range, however, each observation shows a good indication for emission from the general direction of CTA 102 and 3C 454.3, although none of the individually observed excesses exceeds the  $4\sigma$  level. In observations 19 and 26+28, the observed emission is centered roughly between the two quasars and cannot be uniquely identified with either of the two. The location of the excess seen in observation 37 appears to favour CTA 102 as the origin of the observed emission.

In view of this poor evidence for detection of the two quasars in the individual observations, we have combined all available data. Again, no convincing evidence for emission below 10 MeV was found. Figure 1 shows the maximum-likelihood map of the combined observations in the 10–30 MeV energy range. The quantity shown in this figure is  $-2 \ln \lambda$ , where  $\lambda$  is defined as the ratio of the likelihood  $L(\text{background})$  and the likelihood  $L(\text{source}+\text{background})$ . This quantity has a  $\chi^2$  distribution with 1 degree of freedom in the case of a known source position. However, because of the background filtering technique used in the present work the significance of a source detection is slightly smaller than derived from the standard interpretation of the likelihood-ratio (see Bloemen et al. 1993).

Table 1: *COMPTEL* observations of CTA 102 and 3C 454.3 in 1992 during the sky-survey phase of CGRO (observation numbers in CGRO notation). The angular distance refers to the angle between the instrument pointing direction and the source location.

#	Date	Date	Eff. exp. days	Angular distance to	
	start	end		CTA 102	3C 454.3
19	Jan 23	Feb 06	10.4	14°	20°
26	Apr 23	Apr 28	2.4	24°	18°
28	May 07	May 14	3.7	24°	18°
37	Aug 20	Aug 27	3.3	21°	15°

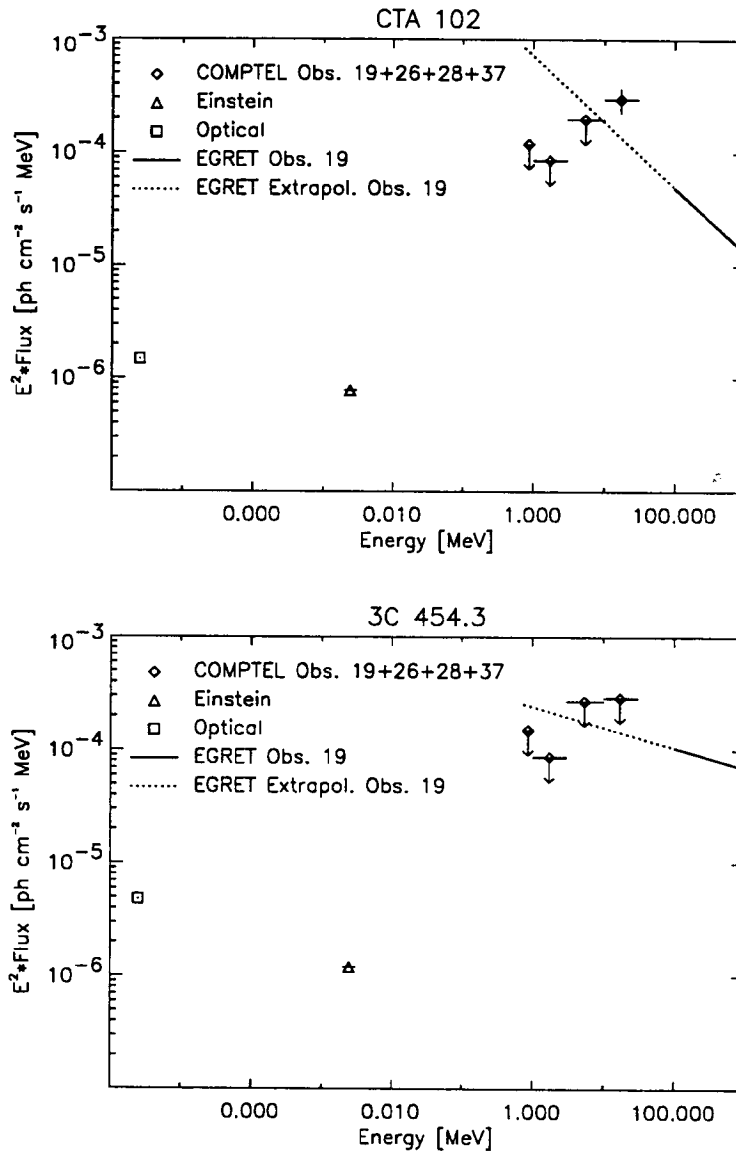


Figure 2: Spectrum of the radiated power per decade of energy for CTA 102 (*top*) and 3C 454.3 (*bottom*), showing the *COMPTEL* results derived from a combination of all four observation periods, together with a compilation of observations at other frequencies. The observations were not obtained simultaneously (see text). The optical data were taken from Padovani (1992) and the *EINSTEIN* X-ray fluxes from Bloom & Marscher (1991).

Figure 1 shows a single significant excess ( $5.7\sigma$ ) located between CTA 102 and 3C 454.3. Since neither of the two is within the 99% error region, we have investigated whether the observed emission can be understood in the case that both CTA 102 and 3C 454.3 contribute. This was done by including two source models in the likelihood analysis, located at the positions of CTA 102 and 3C 454.3, with free flux parameters. We found that this fully fits the observations, i.e. there is no need to invoke a third source. On the other hand, one may feel uncomfortable about the fact that only one excess is seen whereas the two quasars are at sufficiently large angular distance to be resolved by *COMPTEL*. This probably results from

limited statistics, but we cannot exclude that another object is responsible for the observed emission. In fact, at least four other quasars are located near the position of the excess, but none of these shows the blazar properties nor have they been seen by *EGRET*. In any case, should the observed emission not be due to CTA 102 and 3C 454.3, then the conclusions reached in this paper regarding the source spectra would be strengthened.

The spectra of CTA 102 and 3C 454.3 for the combined observations are shown in Figure 2. Note that the figures show energy spectra multiplied by  $E^2$ , i.e. the quantity shown is proportional to the radiated power per decade of energy. Since the imaging results indicated that both CTA 102 and 3C 454.3 may contribute to the observed emission, we have determined the flux values by fitting *simultaneously* two sources in the likelihood analysis.

Also shown in Fig. 2 are the *EGRET* power-law spectra obtained for observation 19 (Nolan et al. 1993, Hartman et al. 1993). Spectral information from the other *EGRET* observations is not available yet, but the published integral flux values are within uncertainties identical to the measured fluxes in observation 19. It seems clear that the power-law spectra measured by *EGRET* above  $\sim 50$  MeV demand a flattening at a few MeV. Although the optical and X-ray observations included in the figures were not obtained simultaneously, they clearly indicate that the emitted power of both quasars strongly peaks at MeV energies.

In conclusion, the *COMPTEL* observations of CTA 102 and 3C 454.3 clearly indicate that the power-law spectra measured by *EGRET* above  $\sim 50$  MeV show a flattening at lower MeV energies. A comparison with observations at other wavelengths shows that the power spectra of CTA 102 and 3C 454.3 peak at MeV energies. This behaviour appears to be a common feature of AGNs radiating at gamma-ray energies. A more detailed discussion is given by Blom et al. (1993).

#### REFERENCES

- Blandford, R.D., Königl, A., 1979, ApJ **232**, 34  
 Bloemen, H., Hermsen, W., Swanenburg, B.N. et al., 1993, ApJS, in press  
 Blom, J.J., Bloemen, H., Bennett, K. et al., 1993, A&A, submitted  
 Bloom, S.D., Marscher, A.P., 1991, ApJ **366**, 16  
 de Boer, H. et al., 1992, in "Data Analysis in Astronomy IV" eds. V. Di Gesù et al., Plenum Press, New York, Vol.59, p.241  
 Collmar, W., Bennett, K., Bloemen, H. et al., 1993, ICRC, Calgary, in press  
 Fichtel, C.E., Bertsch, D.L., Hartman, R.C. et al., 1993, A&AS **97**, 13  
 Hartman, R.C., Bertsch, D.L., Dingus, B.L. et al., 1993, ApJ **407**, L41  
 Hermsen, W., Aarts, H.J.M., Bennett, K. et al., 1993, A&AS **97**, 97  
 Nolan, P.L., Bertsch, D.L., Fichtel, C.E. et al., 1993, APJ **414**, 82  
 Padovani, P., 1992, MNRAS **257**, 404  
 Schönfelder, V. et al., 1993, ApJS **86**, 657  
 Steinle, H., Bloemen, H., Collmar, W. et al., 1992, in "COSPAR World Space Congress", Washington, in press  
 Strong, A. et al., 1991, in "Data Analysis in Astronomy IV" eds. V. Di Gesù et al., Plenum Press, New York, Vol.59, p.251