1-1993

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Comments

Recommended Citation

W. Hermsen, H.J.M. Aarts, K. Bennett, H. Bloemen, H. de Boer, W. Collmar, A. Connors, R. Diehl, R. van Dijk, J.W. den Herder, L. Kuiper, G.G. Lichti, J. Lockwood, J. Macri, M. McConnell, D. Morris, R. Much, J.M. Ryan, V. Schönfelder, G. Simpson, H. Steinle, A.W. Strong, B.N. Swanenburg, C. de Vries, W. Webber, and C. Winkler. COMPTEL detections of the quasars 3C 273 and 3C 279. 1993, Astron. Astrophys. Suppl., v. 97, no. 1, pp. 97-100.

ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

JANUARY 1993, PAGE 97

Astron. Astrophys. Suppl. Ser. **97**, 97-100 (1993)

COMPTEL detections of the quasars 3C 273 and 3C 279

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Received June 3; accepted September 2, 1992

Abstract. — The COMPTEL experiment aboard the Compton Gamma Ray Observatory, sensitive in the energy range from $\sim$ 0.7 to 30 MeV, observed the high latitude region containing 3C 273 and 3C 279 during a 2-week period in June, 1991. A search for sources using a Maximum Likelihood Analysis revealed two statistically significant point-like excesses, the positions of which are consistent with those of 3C 273 and 3C 279. These sources are the first QSO's detected at MeV energies. In the Comptel energy domain their spectra appear to be greatly different. A comparison with earlier and simultaneous measurements in neighbouring energy ranges indicates that 3C 273 reaches its maximum luminosity at a few MeV while 3C 279 remains at its maximum level from $\sim$ 10 MeV up to a few GeV.

Key words: gamma-rays — quasars: 3C 273, 3C 279.

1. Introduction.

The Compton Gamma Ray Observatory (CGRO) was launched by NASA on April 5, 1991. The imaging Compton telescope COMPTEL is one of four instruments aboard GRO. COMPTEL operates in the energy range between $\sim$ 0.7 MeV and 30 MeV with a field of view of $\sim$ 1 steradian, a position determination accuracy of $\sim 0.5°$ and an energy resolution better than 10% *FWHM* (Schönfelder *et al.* 1992). The High Energy Gamma-Ray Telescope (EGRET) aboard CGRO operates at higher energies (30 MeV–30 GeV) and the Oriented Scintillation Spectrometer Experiment (OSSE) at lower energies (100 keV–10 MeV) than COMPTEL.

The detection of the quasar 3C 273 ($z = 0.158$) in the COS-B data at energies above 50 MeV (Swanenburg *et al.* 1978) indicated the importance of CGRO observations of quasars. Interpolation between the then existing hard-X-ray detections up to $\sim$ 120 keV (Primini *et al.* 1979; Ricker *et al.* 1980; Pietsch *et al.* 1981) suggested that 3C273 would reach its maximum luminosity in the soft gamma-ray range, making it a target of particular importance to COMPTEL. Furthermore, after the discovery by COS-B no consistent scenario could be proposed for this source which explained the overall spectrum including the luminous hard gamma-ray tail.

The pointing towards the region containing 3C 273 was therefore one of the first in the CGRO observation programme. Early inspection of the EGRET data revealed a surprise: a strong gamma-ray source was detected in the direction of the optically violent variable (OVV) quasar 3C 279 ($z = 0.538$) (Hartman *et al.* 1992). This source, which is $\sim 10°$ from 3C 273, outshone 3C273 in the EGRET data above 70 MeV.

This paper reports on the search in the Comptel data for low-energy gamma-ray emission from the quasars 3C 273 and 3C 279.

2. Data and analysis method.

COMPTEL viewed the region containing 3C 273 and 3C 279 between June 15 and June 28, 1991, and between October 3 and October 17, 1991. The present results are derived from the first observation.

A Maximum Likelihood Method was used to search for sources; in short, for each position within the COMPTEL field of view the maximum likelihood can be calculated for only a background distribution explaining the

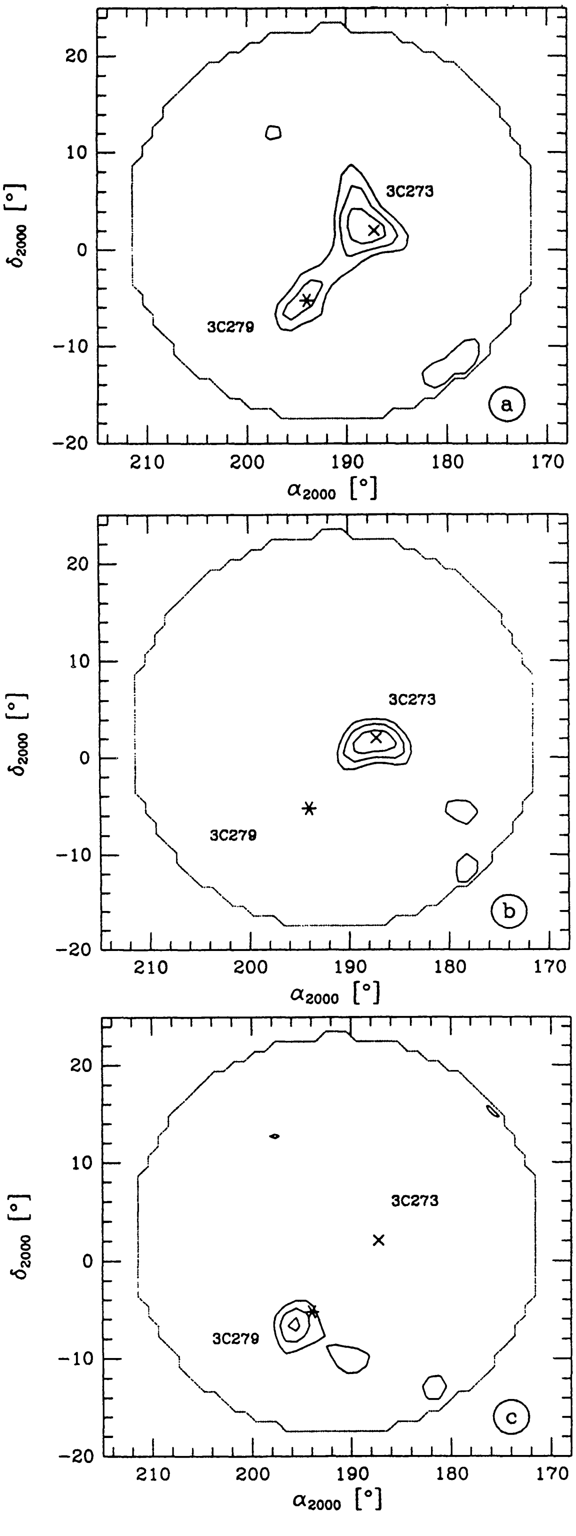


FIGURE 1. Maximum-likelihood-ratio (λ) maps: a) sum of the λ-maps for 1–3 MeV, 3–10 MeV and 10–30 MeV, contour values 20, 25, 30; b) λ-map for 1–3 MeV, contour values 12, 15, 18; c) λ-map for 10–30 MeV, contour values 15, 20, 25.

data ($L(H^0)$), the null hypothesis H^0, as well as for a background distribution plus pointlike source ($L(H^1)$). The Maximum Likelihood ratio for these tests provides a measure for the likelihood that a source has been detected. In a classical interpretation, the parameter $\lambda = 2\log(L(H^1)/L(H^0))$ is distributed as $\chi_q{}^2$ under the null hypothesis H^0, with q the number of free parameters that are added to the null hypothesis. The application of the Maximum Likelihood Method in the 3-dimensional COMPTEL dataspace is described in detail by de Boer *et al.* (1992). The 3-dimensional energy dependent response to a point source is described by Diehl *et al.* (1992).

The data space used had a binning of 1° in the spatial coordinates and 2° in the measured Compton scatter angle $\bar{\varphi}$. The background was estimated from the measured data by an averaging technique based on data pixels adjacent to the source response pixels in the 3-dimensional dataspace. This approach efficiently suppresses point-source signals, yet preserving the general background structure (instrumental and large-scale extragalactic and galactic background). The analysis has so far been performed in the three energy intervals 1–3, 3–10, and 10–30 MeV.

3. Maximum-likelihood-ratio maps.

For each energy interval a maximum-likelihood-ratio map has been produced on a 1° × 1° grid. Figure 1a shows the sum of these three maps, giving the combined evidence for the presence of sources in the field of view. At the position of 3C 273 and 3C 279 the λ-values demonstrate that both sources are detected by COMPTEL. Converting the likelihood values into probabilities of random fluctuations simulating these sources gives for 3C 273 a probability of about 6×10^{-7} and for 3C 279 6×10^{-6}.

The two sources appear to exhibit remarkably different spectral shapes. This is immediately obvious in Figures 1b and 1c. For energies between 1 and 3 MeV Figure 1b clearly shows 3C 273 (probability 8×10^{-6}), while at the position of 3C 279 no enhancement is visible. In the high-energy channel it is the other way around: 3C 273 is not detected, while Figure 1c shows 3C 279 between 10 and 30 MeV (probability 6×10^{-5}). The latter probability of detection is calculated for the actual position of 3C 279 and not for the maximum in the map, which is $\sim 2°$ displaced from the position of 3C 279. Simulations have shown that such a displacement for a weak source signal on the high COMPTEL background can be explained by statistical fluctuations. The better statistics in the sum of the data between 3 and 30 MeV give a maximum at the position of 3C 279 (see e.g. Figure 1a).

4. Energy spectra.

With the Maximum Likelihood Method, flux values can be determined in the selected three energy ranges. Since the 3-dimensional point-spread function is energy dependent, an input energy spectrum has to be assumed to obtain accurate flux values. In practice a single iteration using the spectrum found from the initial assumption is sufficient to obtain a self-consistent result. However, in this initial analysis, for each source only two data points and one upper limit can be derived (see Tab. 1). Therefore the COMPTEL data alone do not give narrow limits on a spectral index, but the overall GRO spectrum can provide a better estimate of the real spectral shape.

Figure 2a shows the differential energy spectrum for 3C 273, the new COMPTEL measurements in the middle with both earlier and contemporaneous measurements at lower and higher energies. The COMPTEL values are consistent with an $E^{-2.3}$ spectrum, and extrapolate smoothly to the EGRET measurement. The spectrum measured up to a few MeV by OSSE in June 1991, is consistent with the COMPTEL low-energy point (J. Kurfess, private communication).

The derived differential spectrum of 3C279 is shown in Figure 2b. The COMPTEL flux values alone indicate a hard spectrum (power-law index -1.3 to -1.6), but the flux for the interval 10–30 MeV is consistent with an E^{-2} extrapolation from the high-energy spectrum measured by EGRET (Hartman *et al.* 1992).

TABLE 1. *Measured fluxes with 1σ statistical uncertainties and 2σ upper limits of 3C 273 and 3C 279 in units of* 10^{-5} *ph* cm^{-2} s^{-1}.

$E_1 - E_2$	$1-3$ MeV	$3-10$ MeV	$10-30$ MeV
3C273	14.8 ± 2.4	3.6 ± 0.9	0.6
3C279	2.6	3.6 ± 1.2	2.0 ± 0.4

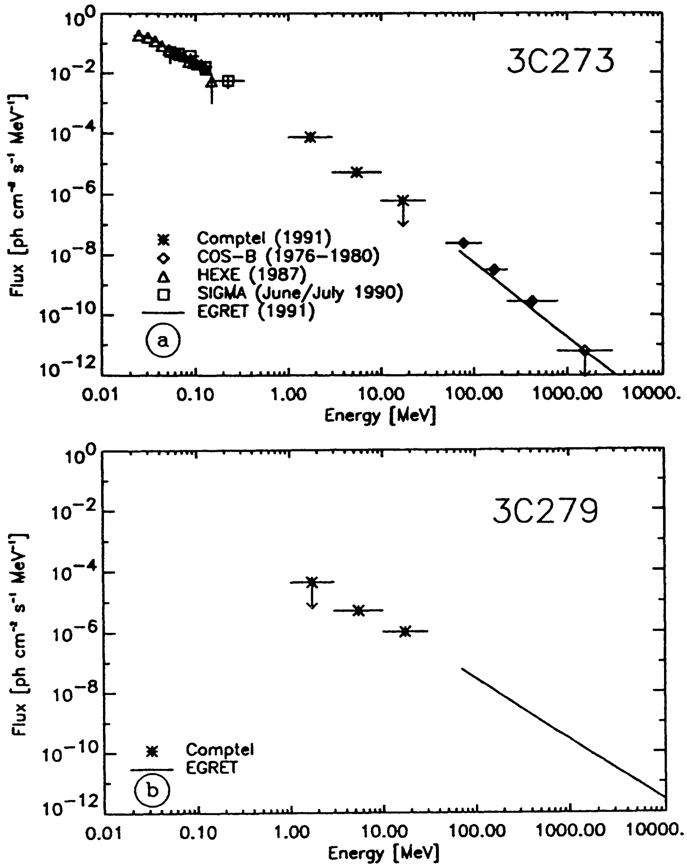


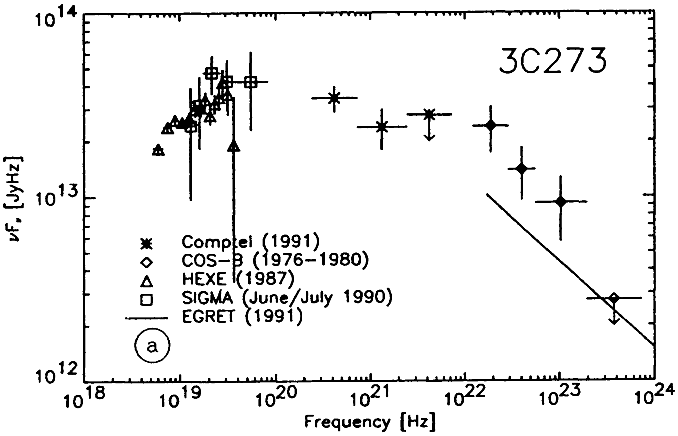
FIGURE 2. Differential energy spectra: a) 3C 273, COMPTEL fluxes together with spectra from COS-B (Hermsen *et al.* 1981), HEXE (Maisack *et al.* 1992), SIGMA (Bassani *et al.* 1992) and EGRET (von Montigny *et al.* 1992); b) 3C 279, COMPTEL fluxes with EGRET spectrum (Hartman *et al.* 1992). COMPTEL upper limits are 2σ; The COMPTEL 1σ statistical uncertainties and the systematic ones are smaller than the used symbols.

5. Discussion.

These COMPTEL measurements yield the first detections of quasars at low-energy gamma rays, while providing evidence that the gamma-ray signatures of quasars can be very different at these energies, as can be seen in Figures 2a and 2b. This contrasts the situation in the X-ray region where OVVs like 3C 279 are indistinguishable from radio loud quasars like 3C 273. The difference becomes even more evident in the 'luminosity' spectra shown in Figures 3a and 3b. 3C 273 reaches its maximum energy output per logarithmic energy interval near 1 MeV, as suggested 10 years ago (Bignami *et al.* 1981), while for 3C 279 this maximum is reached for energies from $\sim$ 10 MeV up to energies as high as a few GeV. In fact the combination of the EGRET and COMPTEL spectra for 3C 279 points to a break energy of about 10 MeV. The spectrum below this energy is then consistent with a power-law extrapolation towards the X-ray range with an index of -1.2 to -1.4.

Measurements from the radio up to the X-ray domain show that 3C 279 is occasionally in a high state of activity, during which its energy output can be enhanced by up to an order of magnitude (see Fig. 3b). Although the EGRET data showed that 3C 279 was 'flaring up' over the first week of the GRO observation in June 1991 (Kanbach *et al.* 1992), extrapolation of the hard COMPTEL spectrum below 10 MeV to lower energies is consistent with a low state of activity in X-rays. This has been confirmed by contemporaneous Ginga measurements (presentation by Makino, this conference). The apparent lack of correlation in X-ray - and gamma-ray activity is of particular importance for the construction of source scenarios.

If the emissions from the quasars are isotropic, the absolute gamma-ray luminosity of 3C 273 reaches $\sim 6 \times 10^{46}$ erg s^{-1} at $\sim$ 1 MeV (for $H_0 = 75$ km s^{-1} Mpc^{-1}),



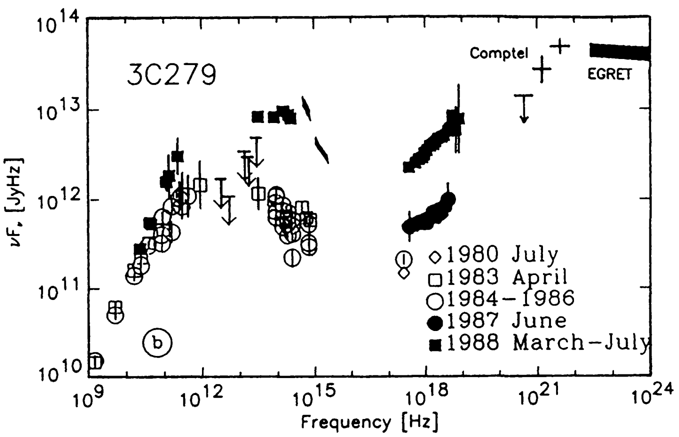


FIGURE 3. 'Luminosity' spectra of 3C 273 and 3C 279. a) The same data as in Figure 2a, but now showing the energy output per logarithmic energy interval. b) COMPTEL and EGRET (Hartman *et al.* 1992) spectra together with measurements at lower frequencies for quiescent (open symbols), and enhanced (filled symbols) periods. The X-ray data are from Ginga measurements; for references see Makino *et al.* 1989. For 3C 279, the COMPTEL values have been calculated for 10–30 MeV assuming an E^{-2}-spectrum (measured by EGRET) and below 10 MeV for an $E^{-1.4}$ spectrum. The COMPTEL error bars are statistical only.

and as high as a few 10^{48} erg s^{-1} from 10 MeV up to a few GeV for 3C 279. In fact, Bezler *et al.* (1984) measured 3C 273 between 20 and 200 keV with a luminosity of about 8×10^{46} erg s^{-1} (for the same H_0) with a hard spectrum (index -1.2), suggesting that 3C 273 sometimes reaches luminosities around 1 MeV of comparable magnitude to that detected by EGRET in June 1991 for 3C 279.

Acknowledgements.

The authors thank Richard Sebus for his assistance in the analysis.

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