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# THE 1993 MULTIWAVELENGTH CAMPAIGN ON 3C 279: THE RADIO TO GAMMA-RAY ENERGY DISTRIBUTION IN LOW STATE

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## ABSTRACT

Simultaneous observations of 3C 279 at radio, millimeter, near-infrared, optical, ultraviolet (with *IUE*) and X-ray (with *ROSAT*) wavelengths were obtained in 1992 December–1993 January, during a three week pointing at the source by the *Compton Gamma Ray Observatory*. The blazar was in a quiescent or "low" state during this period. Comparing the multiwavelenth energy distribution to that from 1991 June, when 3C 279 was in its brightest recorded $\gamma$-ray state, we find the following:

1. 3C 279 faded dramatically at all frequencies above $10^{14}$ Hz, while the flux variations at low frequencies (radio to millimeter wavelengths) were minor.
2. The near-infrared-optical-ultraviolet spectral shape was softer (steeper) in the quiescent state, and the X-ray spectra also appear softer, although the spectral indix measured by *ROSAT* refer to a lower energy band than that measured earlier with *Ginga.*
3. The ratio of the $\gamma$-ray luminosity to that across all other frequencies decreased from a value of $\simeq 10$ in the flaring state to a value $\simeq 1$ in the quiescent state.

These findings imply that the production of $\gamma$-rays is closely related to the optical-ultraviolet continuum, in agreement with models where $\gamma$-rays are produced through inverse Compton (IC) scattering by relativistic electrons emitting the synchrotron continuum. The observed nonlinear relation between the synchrotron and IC requires both a change in the electron spectrum and an associated change in the seed photons.

*Subject headings:* galaxies: active — galaxies: individual (3C 279) — galaxies: jets — gamma rays: observations — quasars: general — ultraviolet: galaxies — X-rays: galaxies

## 1. INTRODUCTION

The recent discovery of $\gamma$-ray emission from blazars (Hartman 1992; Hartman 1993 and references therein) represents a fundamental advance in our observational knowledge about these enigmatic objects. The power output in the 100–1000 MeV range of blazars detected by the *Compton Gamma Ray Observatory* (*CGRO*) is comparable to, and in several cases exceeds, that in the rest of the electromagnetic spectrum. Thus, explaining the $\gamma$-rays is of key importance for a theoretical understanding of these objects, which include BL Lac objects and optically violently variable or high polarized quasars. Various models have been proposed, the majority favoring the inverse Compton (IC) mechanism for $\gamma$-ray production (for reviews see Sikora 1994; Maraschi, Chisellini, & Celotti 1994, hereafter MGC; Marscher & Bloom 1994). Since the spectrum from radio to UV frequencies is commonly interpreted as synchrotron radiation from high-energy electrons (e.g., Königl 1989; Marscher 1993), the same electrons can produce $\gamma$-rays by upscattering either the synchrotron photons or other photons external to the jet. In both cases a strong correlation

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between the synchrotron and IC emission is predicted. The exact quantitative relation depends on the specific model, and the study of the simultaneous variations of the synchrotron (millimeter to ultraviolet to soft X-rays) and IC (X-rays to $\gamma$-rays) components offers a unique opportunity to constrain the models.

Therefore, we organized a large observational campaign to obtain simultaneous data at all available wavelengths, from radio to $\gamma$-rays, on 3C 279, which at the time was the brightest extragalactic $\gamma$-ray source observed. The observing dates (1992 December–1993 January) were chosen to allow simultaneous observation by three spacecraft—*IUE*, *ROSAT*, and *CGRO*—and from ground-based observatories.

Since $\gamma$-ray variability on a timescale of days had been detected previously in 3C 279 (Kniffen et al. 1993), the program aimed at studying the correlation of variability in different frequency bands within a 20 day time interval. However, the source was found to be in a quiescent or "low" state in $\gamma$-ray emission: COMPTEL obtained an upper limit, while the sensitivity of the EGRET instrument was barely sufficient to derive an average flux over the entire period. Nevertheless, owing to the excellent wavelength coverage resulting from the contributions of the numerous observers, we could derive a good multifrequency spectrum for the quiescent state, presented in § 2. The full data set will be presented in separate papers devoted to the coordinated VLBI (Wehrle et al. 1994), radio to optical (Grandi et al. 1994), and UV to X-ray observations (Urry et al. 1994). In § 3 the 1993 energy distribution is compared with that observed in 1991 June, the epoch of the highest measured $\gamma$-ray flux, and the results are discussed in § 4.

## 2. OBSERVATIONS

The EGRET instrument on the *Compton Gamma Ray Observatory* observed 3C 279 with good sensitivity (7° off-axis) from 1992 December 22 to 1993 January 12. The summed data for the entire 3 week observation were analyzed, as were three separate 1 week intervals. 3C 279 was not detected at the $\geq 4\ \sigma$ level (the minimum used by the EGRET team) in any of the four analyses. However, in each of them a weak source (3.5 $\sigma$ for the summed data, 3 $\sigma$ for the separate weeks) appeared to be present at a position consistent with that of 3C 279. The integral flux for a source at the true position of 3C 279 is $(1.2 \pm 0.4) \times 10^{-7}$ photons cm$^{-2}$ s$^{-1}$ above 100 MeV, averaged over the entire 3 week observation. This value was converted to the appropriate units, reported in Table 1, assuming a photon spectral index of $\Gamma = 2$. It should be kept in mind that the detection is marginal.

The COMPTEL instrument did not detect the source but provided 2 $\sigma$ upper limits of 4.7, 7.6, 3.4, and $1.2 \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$ in the energy bands of 0.75–1, 1–3, 3–10, and 10–30, MeV, respectively. Only the most stringent limit, adjacent to the EGRET sensitivity range, is reported in Table 1; conversion to flux assumed a photon spectral index of $\Gamma = 2$.

TABLE 1

3C 279 MULTIFREQUENCY DATA

| Observers | Instrument | Date | $n$[a] | log $\nu$ | log $f$(Jy)[b] |
|---|---|---|---|---|---|
| Hartman | *GRO*/EGRET<br>(0.1–5 GeV) | 1992 Dec 22–1993 Jan 12 | 1 | 22.38 | $-10.09^{+0.13}_{-0.18}$ |
| Collmar | *GRO*/COMPTEL<br>(10–30 MeV) | 1992 Dec 22–1993 Jan 12 | 1 | 21.62 | $-8.16$ (upper limit) |
| Fink and Thomas | *ROSAT*/PSPC<br>(0.1–2.4 keV) | 1993 Jan 2–5 | 24 | 17.38 | $-5.99 \pm 0.01$ |
| Maraschi and Urry | *IUE*/SWP<br>(1600–1650 Å) | 1993 Jan 2–5 | 2 | 15.27 | $-4.00^{+0.13}_{-0.18}$ |
|  | *IUE*/LWP<br>(2600–2700 Å) | 1993 Jan 2–5 | 4 | 15.05 | $-3.54^{+0.04}_{-0.05}$ |
| Bailyn and Méndes | CTIO (0.9 m)<br>(*BVRI*) | 1993 Jan 3–6 | 4 | 14.83 | $-3.30^{+0.03}_{-0.07}$ * |
|  |  | 1993 Jan 3–6 | 4 | 14.73 | $-3.12^{+0.05}_{-0.06}$ * |
|  |  | 1993 Jan 3–6 | 4 | 14.67 | $-2.98^{+0.05}_{-0.06}$ * |
|  |  | 1993 Jan 3–6 | 4 | 14.58 | $-2.80^{+0.06}_{-0.07}$ * |
| Wagner and Bock | Landessternwarte Heidelberg telescope<br>(*R*) | 1993 Jan 1–6 | 5 | 14.67 | $-2.98^{+0.08}_{-0.08}$ * |
| Glass | 1.9 m Sutherland telescope<br>(*JHK*) | 1993 Jan 12 | 1 | 14.40 | $-2.58 \pm 0.04$ |
|  |  | 1993 Jan 12 | 1 | 14.25 | $-2.35 \pm 0.02$ |
|  |  | 1993 Jan 12 | 1 | 14.15 | $-2.10 \pm 0.01$ |
| McHardy et al. | JCMT<br>(0.8, 1.1, and 2.0 mm) | 1993 Jan 14 | 1 | 11.57 | $0.72^{+0.02}_{-0.03}$ |
|  |  | 1992 Dec 30–1993 Jan 14 | 2 | 11.43 | $0.89^{+0.03}_{-0.04}$ |
|  |  | 1992 Dec 29–1993 Jan 14 | 2 | 11.18 | $0.93 \pm 0.03$ |
| Steppe and Reuter | IRAM<br>(90 and 230 GHz) | 1993 Jan 1–7 | 4 | 11.36 | $0.84 \pm 0.02$ |
|  |  | 1993 Jan 1–8 | 6 | 10.95 | $1.20 \pm 0.01$ |
| Teräsranta | Metsähovi station<br>(22 and 37 GHz) | 1993 Jan 4–9 | 3 | 10.57 | $1.25^{+0.03}_{-0.02}$ * |
|  |  | 1993 Jan 2–9 | 6 | 10.34 | $1.19 \pm 0.01$ |
| Aller and Aller | Michigan station<br>(4, 8, 8.0, and 14.5 GHz) | 1993 Jan 1 | 1 | 10.16 | $1.14 \pm 0.01$ |
|  |  | 1993 Jan 1–7 | 2 | 9.90 | $1.09 \pm 0.01$ |
|  |  | 1993 Jan 3 | 1 | 9.58 | $1.02 \pm 0.01$ |

[a] Number of observations used to compute the average flux.

[b] 1 $\sigma$ uncertainty. An asterisk denotes suspected variability. The reported values correspond to the maximum and minimum observed flux.

*ROSAT* Position Sensitive Proportional Counter (PSPC) observations were arranged to cover the whole period (1992 December 27–1993 January 15) with one observation per day plus more intensive coverage (24 observations) between 1993 January 2 and 5. Throughout the observations, the spectra are well fitted by a simple absorbed power-law model, with a column density in close agreement with the galactic $N_{\rm H}$ measured by Elvis, Lockman, & Wilkes (1989). In this *Letter* we use the average spectrum obtained during the latter period. The derived photon spectral index and column density are respectively $\Gamma_X = 1.91 \pm 0.07$ and $N_{\rm H} = (2.35 \pm 0.18) \times 10^{20}$ cm$^{-2}$. The 1 keV flux is reported in Table 1. No large-amplitude (greater than 15% rms) variability is seen in the *ROSAT* data, within either the intensive or the extended monitoring period.

Fourteen spectra were obtained with *IUE* between 1992 December 25 and 1993 January 12: 10 exposures of ~180 minutes in the long-wavelength camera and four 14 hr exposures in the short-wavelength camera. All of them had poor signal-to-noise ratios. Details of the analysis will be described elsewhere (Urry et al. 1994). Here we use average fluxes in short- and long-wavelength bands derived from the spectra obtained in the period between 1993 January 2 and 5 (four LWP and 2 SWP; see Table 1), simultaneously with the intensive coverage with *ROSAT*. The fluxes reported in Table 1 have been dereddened with $E(B-V) = 0.015$.

The ground-based observations involved many telescopes and observers at various dates; they will be described extensively elsewhere (Grandi et al. 1994). The best temporal sampling occurred at the beginning of January when all the space-based instruments and most of the ground-based telescopes could simultaneously (within less than a day) observe the source. Bad weather prevents only the James Clerk Maxwell Telescope (JCMT) millimeter and near-infrared wavelengths from being strictly simultaneous with the spacecraft observations (see Table 1). In order to construct the broadband energy distribution of 3C 279, we therefore used in each wave band average flux values of the observations performed in the time intervals specified in Table 1. All flux values and additional information are given in Table 1.

## 3. COMPARISON OF THE 1992/1993 AND 1991 ENERGY DISTRIBUTIONS

The energy distribution of 3C 279 derived from this campaign is shown in Figure 1, together with that measured in 1991 June when the maximum $\gamma$-ray flux was observed (from references listed below and in Hartman et al. 1993).

Data for the bright state of 1991 June were obtained by M. Aller (4.8, 8.0 and 14.5 GHz), H. Teräsranta (22 and 37 GHz), and I. McHardy (millimeter, submillimeter, and infrared wavelengths). Optical, UV, X-ray, and $\gamma$-ray fluxes were taken from the literature (Takalo et al. 1992; Bonnell, Vestrand, & Stacy 1994; Makino et al. 1992; Hermsen et al. 1993; Kniffen et al. 1993). With the exception of the optical data, all the observations were conducted while the *CGRO* satellite was pointing at the source (1991 June 16–28) or close to that period (the radio [22 GHz] and UV observations were obtained respectively before [June 7] and after [July 29] the $\gamma$-ray measurements). The nearest published *BVRI* magnitudes (used in Fig. 1) date from 1991 February 6.

Comparing the 1992 December/1993 January and 1991 June energy distributions, it is striking that in 1993 the source was much fainter than in 1991 at all frequencies above $10^{14}$ Hz, while at lower frequencies the variations between the two states were minor. Data taken when 3C 279 was between flaring and quiescent states indicate that the emission from $10^{14}$ to $10^{23}$ Hz probably varies in a correlated fashion, at least on timescales of months (Grandi et al. 1994).

In the near-infrared through ultraviolet wavelength region, the spectral shape varies, being softer in the fainter state. This

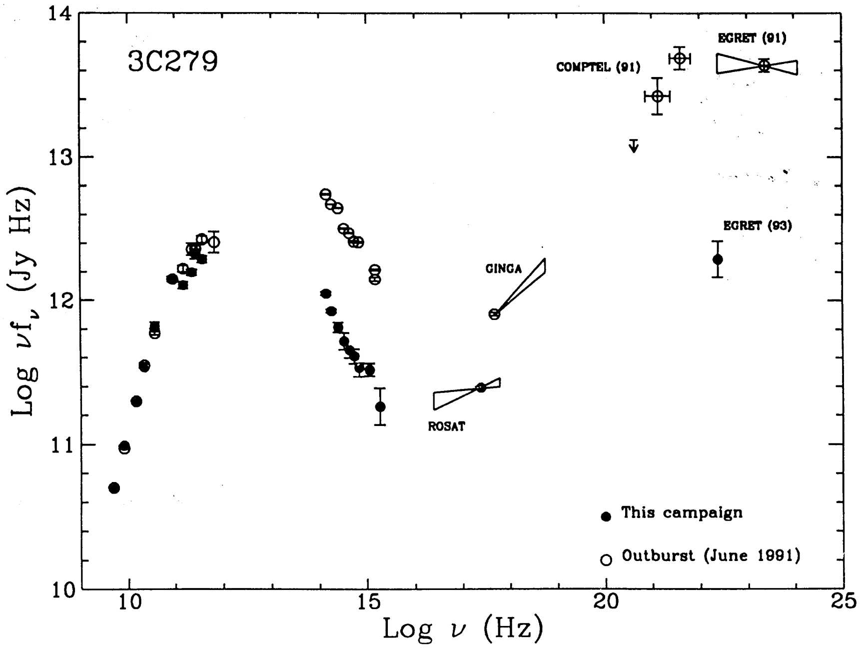

FIG. 1.—Radio to $\gamma$-ray energy distribution of 3C 279 as derived from the quasi-simultaneous observations from 1992 December to 1993 January presented in this *Letter* (*filled symbols*). Data referring to 1991 June, mostly taken from the literature, are shown for comparison (*open symbols*). The COMPTEL upper limit refers to the 1991 observation.

result was derived also within the UV band alone, by studying archival *IUE* data (Bonnell et al. 1994; Urry et al. 1994). The ratios between the high-state and low-state fluxes are 6.5 at $3 \times 10^{14}$ Hz and 11 at $10^{15}$ Hz.

At X-ray and gamma-ray frequencies, the 1991 to 1992/1993 flux ratios are 3 at $4.8 \times 10^{17}$ Hz (2 keV) and 20 at $2.4 \times 10^{22}$ Hz (100 MeV). The *ROSAT* spectrum is significantly softer than the *Ginga* spectrum, consistent with the spectral softening seen at other wavelengths, but because the energy bands overlap only marginally, we cannot exclude the possibility that the change in spectral shape depends on wavelength rather than on time. Unfortunately, no information on the spectral shape in the $\gamma$-ray band can be derived for the quiescent state, since the detection was marginal for EGRET, and COMPTEL provided only an upper limit.

Finally, the ratio of the integrated $\gamma$-ray flux to the integrated flux in all the other observation bands varied substantially between the two epochs, the luminosity in $\gamma$-rays being comparable to that in other frequency bands in the low state, while in the brightest state the $\gamma$-ray luminosity exceeded that in other bands by a factor of 10.

## 4. DISCUSSION

At both epochs the broadband energy distribution of 3C 279 in the $\nu F_\nu$ representation (Fig. 1) is rising in the radio through millimeter band, falling in the IR through UV band and rising again in the X-ray band. From the available, admittedly incomplete, wavelength coverage, the spectral energy distribution of 3C 279 appears to consist of two broad components, with presumable peaks in the millimeter to infrared range and in the 10 GeV to 1 GeV range.

The first broad spectral component is commonly interpreted as synchrotron radiation by high-energy electrons in a relativistic jet, which is self-absorbed at centimeter wavelengths. The second, shorter wavelength component has been interpreted as IC scattered radiation by the same population of relativistic electrons responsible for the synchrotron emission.

The seed photons to be upscattered could be the synchrotron photons themselves, as in the synchrotron self-Compton (SSC) model (Maraschi, Ghisellini, & Celotti 1992; Bloom & Marscher 1993), or photons external to the jet. The latter may derive from an accretion disk (Dermer, Schlickeiser, & Mastichiadis 1992; Dermer & Schlickeiser 1993) and could possibly be isotropized by scattering in a hot intercloud medium and/or may be emitted by the broad-line region itself (Blandford 1993; Sikora, Begelman, & Rees 1994). The relative importance of the two types of seed photons (synchrotron or external), estimated on the basis of observed quantities, depends on a high power of the beaming factor ($\sim\delta^5$; Sikora et al. 1994). However, in neither case is it easy to reproduce the observed energy distributions accurately with a simple homogeneous model; multiple components or an inhomogeneous jet are required.

A detailed fit to the data with multiparameter models is beyond the scope of this *Letter*, but on the basis of the extraordinary observed variability some general remarks can be made. In the case of the simplest SSC model, the most important photons for upscattering are those at the peak of the synchrotron emission (i.e., $10^{13}$–$10^{14}$ Hz). The similarity of the spectral shapes of the synchrotron and IC components suggests that these photons are upscattered to the $\gamma$-ray band ($10^{22}$–$10^{23}$ Hz), which requires a relatively high electron factor, $\gamma \sim 10^4$, and a rather low magnetic field, $B = 0.3(\gamma/10^4)^{-2}\delta^{-1}$ G,

External seed photons, even if isotropic in the rest frame of the active galactic nucleus, would appear blueshifted and therefore enhanced in the jet frame. The typical frequency of accretion disk or broad-line photons as seen from the jet would be in the extreme ultraviolet/soft X-ray band, thus providing an IC $\gamma$-ray component peaking at higher energies than in the case of the SSC mechanism (for the same mean electron Lorentz factor) and/or allowing for higher values of the magnetic field (e.g., MGC).

With regard to variability, a general property of the SSC model is that, when the electron distribution decreases in number and/or average square energy, the synchrotron luminosity decreases proportionately while the IC ($\gamma$-ray) luminosity decreases quadratically (e.g., MGC).

If, instead, the photon energy density as seen in the jet frame is dominated by external photons, when the electron spectrum varies the synchrotron and IC emission components will both scale proportionately, unless the external photon field varies at the same time and in the same sense as the electron spectrum.

The energy distributions of 3C 279 in high and low state are qualitatively consistent with the SSC model, since the $\gamma$-ray luminosity, assumed to represent the IC luminosity, varies more than the observed synchrotron luminosity. However, one can still salvage the external photon models fairly naturally by postulating that the synchrotron decrease is caused by a change in the *bulk* Lorentz factor of the radiating electrons. In that case, the external photon field as *seen by the relativistic electrons* also decreases, and if at the same time the spectrum of relativistic electrons in the jet decreases, the resulting variation of the $\gamma$-ray flux is larger than that of the synchrotron flux. A decrease in $\delta$ by a factor of 2 would account for the observed variation in the broad-band energy distribution of 3C 279.

It is interesting to recall that a steepening of the electron distribution is a natural consequence of the diminishing strength of a shock, while a flattening of the electron spectrum is expected if a shock gets stronger or a new shock forms (Schneider & Kirk 1989). Moreover, the relativistic amplification factor for the observed flux (more complicated than a simple Doppler correction; Lind & Blandford 1985 and Celotti, Maraschi, & Treves 1991) could be related to the shock strength. Thus shocks in a jet can qualitatively explain the observed variation in $L_\gamma/L_{\rm bol}$. If external photons dominate the IC mechanism, the shock front should accelerate or slow down substantially when getting respectively stronger or weaker.

## 5. CONCLUSIONS

We obtained a simultaneous multiwavelength energy distribution of 3C 279 in 1993 January. With respect to the energy distribution of 1991 June when the source was in its brightest state in $\gamma$-rays, the fluxes in all wavebands above $\simeq 10^{14}$ Hz were much fainter and the overall energy distribution softer, while only minor variations were observed at the lower frequencies. The largest variation, a factor of about 20, occurred in the $\gamma$-ray power; in the faint state the $\gamma$-ray power was comparable to the power observed at all other frequencies, while in the bright state the $\gamma$-ray power was largely (by a factor of 10) dominant.

The coherent variation of the energy distribution from $10^{14}$ to $10^{23}$ Hz favors models in which the low- and high-frequency components are closely related. This is guaranteed if the same electron population produces the submillimeter to UV continuum through the synchrotron mechanism and the X-ray to $\gamma$-ray continuum by IC scattering ambient photons. In this class of models, the larger variation observed in $\gamma$-rays requires a correlated variation of the electron population *and* of the seed photons.

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