SPECTRAL ENERGY DISTRIBUTIONS OF 3C 279 REVISITED: BeppoSAX OBSERVATIONS AND VARIABILITY MODELS

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ABSTRACT

We present the BeppoSAX observations of 3C 279 performed simultaneously during 1997 January 13–23 with γ-ray pointings with EGRET on board the Compton Gamma Ray Observatory and optical observations at the Torino Observatory (1997 January 11–18). Infrared Space Observatory data close to this epoch are also available. We compare the derived spectral energy distribution (SED) with those obtained at all other epochs with adequate multiwavelength coverage. Simple spectral models fitted to the multiepoch SEDs suggest that changes in intensity can be ascribed mainly to the variation of the bulk Lorentz factor of the plasma in the jet.

Subject headings: quasars: general — quasars: individual (3C 279) — radiation mechanisms: nonthermal — X-rays: galaxies

1. INTRODUCTION

In the last 10 years, about 60 blazars (BL Lac objects and flat-spectrum radio quasars) have been detected in γ-rays by EGRET (Mukherjee et al. 1997; Hartman et al. 1999). The observations show that a large portion of the total power is emitted in this band, and many of these objects exhibit rapid variability (on timescales of hours or days) at the highest energies. The high γ-ray luminosities and short variability timescales impose strong and general constraints on the emitting region; in particular, independent of other evidence, the γ-ray transparency condition implies that the emitting plasma moves relativistically.

The mechanism of γ-ray production is most likely inverse Compton scattering: the seed photons could be produced both within the jet via synchrotron radiation, which is responsible for the emission from radio to UV (synchrotron self-Compton [SSC]; see Maraschi, Ghisellini, & Celotti 1992), and outside the jet (external Compton [EC]) by the accretion disk (Dermer & Schlickeiser 1993) or by the broad-line region (BLR) clouds (Sikora, Begelman, & Rees 1994). The relative weight of the two sources of seed photons is given by the ratio of their respective energy densities as seen in the frame of the emitting matter (Sikora et al. 1994). In flat-spectrum radio quasars, since the external photons typically have much higher frequencies than synchrotron photons, when both processes (SSC and EC) are important, the former dominates the spectral energy distribution (SED) at low energies (in the X-ray band; see Kubo et al. 1998) and the latter in the γ-ray range; significant information about the internal structure of the jet can thus be obtained from observations covering the full X-ray to γ-ray spectral region.

Another open problem is the physical cause of the variability. Flares could be due to propagating shocks causing transient acceleration of relativistic electrons (see, e.g., Marscher & Gear 1985). Recently, an idea initially proposed by Rees (1978) was worked out and applied in particular to 3C 279 by Spada et al. (2001; see also Ghisellini 1999): briefly, the collision of shock fronts travelling in the jet with different bulk Lorentz factors can yield efficient impulsive particle acceleration, leading to enhanced radiation (Spada et al. 2001; Ghisellini 1999).

In any case, both the synchrotron and inverse Compton emission from a single electron population are expected to vary in a correlated fashion, but for a given change in the electron spectrum the amplitudes of the SSC and EC variations will be different (Ghisellini & Maraschi 1996; Sikora 1997). Furthermore, inhomogeneities (clouds) in the medium close to the jet may act as mirrors for the synchrotron photons (Ghisellini & Madau 1996; Boettcher & Dermer 1998; Bednarek 1998). Variability may also result from changes in the beaming factor, because of geometric effects (see Villata & Raiteri 1999). All of these hypotheses predict a particular relative variability in the synchrotron and inverse Compton components, so a study of simultaneous variations in different bands can provide important information about the nature of phenomena occurring in blazar jets.

3C 279 (z = 0.538) was the first blazar discovered as a γ-ray source with the Compton Gamma Ray Observatory (CGRO; Hartman et al. 1992) and is one of the brightest in this band, and as such was the target of several multifrequency campaigns (for the most recent reanalysis of all the data, see Hartman et al. 2001, hereafter H01). It was chosen for observations with BeppoSAX (1997 January 13–23) simultaneous with an EGRET pointing and optical observations (1997 January 11–18) to improve our knowledge of the detailed spectral shape from X-rays to γ-rays.
and to continue the study of its variability at high energies. Since BeppoSAX covers a very wide energy range (0.1–100 keV), it is ideal for studying the connection between the X-ray and γ-ray continuum, where the transition from the SSC to the EC process should take place. In the present work, a complete analysis of the BeppoSAX observations and associated SED are fully presented, combined with a discussion of the historical SEDs of 3C 279 with the best multiwavelength coverage. Preliminary results were published in Maraschi et al. (1998, 2000), Maraschi (2000), and Maraschi & Tavecchio (2001a, 2001b). The BeppoSAX data are also included in H01.

The structure of the paper is the following: in § 2 we present the analysis and results of the BeppoSAX observations of 1997; in § 3 we construct the overall SED of 1997 and compare it with other emission states for which simultaneous or quasi-simultaneous multifrequency data are available; in § 4 we apply a simple spectral model including both the SSC and EC processes to reproduce the observed SEDs at different epochs and derive physical parameters for the emitting plasma. Conclusions are presented in § 5. Throughout the paper we assume \( H_0 = 65 \text{ km s}^{-1} \text{ Mpc}^{-1} \) and \( q_0 = 0.5 \).

2. BeppoSAX OBSERVATIONS OF 1997

The scientific payload of the Italian-Dutch X-ray satellite BeppoSAX\(^9\) (see Boella et al. 1997) consists of four co-aligned narrow-field instruments (NFIs) and two wide-field cameras. Two of the NFIs use concentrators to localize X-rays: the Low Energy Concentrator Spectrometer (LECS; one unit) has a detector sensitive to soft–medium X-ray photons (0.1–10 keV), while the Medium Energy Concentrator Spectrometer (MECS; three units) detects photons in the energy range 1.3–10 keV. The Phoswich Detector System (PDS), nominally sensitive from 15 to 300 keV and consisting of four identical units, uses rocking collimators so as to monitor source and background simultaneously with interchangeable units. We do not consider here data from the fourth NFI, a High Pressure Gas Scintillation Proportional Counter.

The observations of 3C 279 were planned to be simultaneous with a continuous pointing at the source with EGRET and with optical observations performed at the Torino Observatory. They consisted of five pointings, distributed over 10 days (1997 January 13–23) to cover the typical 2 week duration of an EGRET observation. Exposure times and observed count rates in the various detectors are reported in the BeppoSAX journal of observations (see Table 1). We searched for variability both within each observation and between the different observations using the \( \chi^2 \) test against constancy: no significant flux variations were detected; we therefore combined all the observations, deriving a cumulative spectrum.

The BeppoSAX spectral data were analyzed using the standard software packages XSELECT (Version 1.4) and XSPEC (Version 10.0) and the 1997 September version of the calibration files released by the BeppoSAX Scientific Data Center (SDC). From the event files, we extracted the LECS and MECS spectra in circular regions centered around the source with radii of 8' and 6', respectively (see the SAX Analysis Cookbook\(^{10}\)). The PDS spectra extracted with the standard pipeline with the rise-time correction were provided directly by the BeppoSAX SDC.

For the spectral analysis, we considered the LECS data in the restricted energy range 0.1–4 keV, because of unsolved calibration problems at higher energies. PDS data above 180 keV were discarded since the count rate was too close to the instrumental detection limit to be reliable. Background spectra extracted from blank-field observations at the same detector position as the source were used for background subtraction in the LECS and MECS, while for the PDS the simultaneously measured off-source background was used. We fitted rebinned LECS, MECS, and PDS net spectra jointly, allowing for two normalization factors to take into account uncertainties in the intercalibration of different instruments (see the SAX Cookbook).

The total LECS + MECS + PDS spectrum is well described by a single power-law model with an absorption column consistent with the Galactic value \( [N_H] = (2.21 \pm 0.1) \times 10^{20} \text{ cm}^{-2} \), as reported in Elvis, Wilkes, & Lockman (1989); the results of the spectral fits are summarized in Table 2. The residuals of the fit show a weak excess around \( E \approx 0.5 \text{ keV} \) in the LECS data (see Fig. 1, top panel): we modeled the whole spectrum with either a broken power law or a power law with a blackbody component. In both cases, the excess observed at low energy is partly accounted for (see Fig. 1, bottom panel) but requires a column density higher than the Galactic value. In any case, the reduction in \( \chi^2 \) is not significant, and we consider only the power-law model in the rest of our analysis.

All through the analysis, the LECS/MECS normalization ratio was allowed to vary; the best-fit value obtained is 0.85,

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9 See http://www.asdc.asi.it/bepposax.

10 Available at ftp://sax.sdc.asi.it/pub/sax/doc/software_docs/saxabc_v1.2.ps.gz.

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| Instrument | Date       | Start Time | End Time  | Exposure \(10^4\) s | Net Count Rate \(10^{-3}\) counts s\(^{-1}\) |
|-----------|------------|------------|-----------|---------------------|---------------------------------|
| LECS\(^a\) | 1997 Jan 13–23 | 22:55:25   | 23:13:06  | 3.116               | 0.67 ± 0.02                     |
| MECS\(^b\) | 1997 Jan 13–23 | 22:55:25   | 22:45:43  | 8.473               | 1.14 ± 0.01                     |
| PDS\(^c\)  | 1997 Jan 13–23 | 22:55:25   | 21:50:32  | 3.653               | 1.11 ± 0.46                     |

\(^{a}\) Range of 0.1–4.5 keV.

\(^{b}\) Range of 1.8–10.5 keV, 3 MECS units.

\(^{c}\) Range of 15–180 keV.
TABLE 2

| Model                   | $\Gamma^a$ | $\Gamma^b$ | $E_{\alpha}^c$ (keV) | $kT^d$ (keV) | $N_{HI}^e$ $(10^{20} \text{ cm}^{-2})$ | $F_{(2-10 \text{ keV})}^f$ $(10^{-12} \text{ ergs cm}^{-2} \text{ s}^{-1})$ | $\chi^2$/dof |
|-------------------------|------------|------------|----------------------|-------------|----------------------------------------|------------------------------------------------|-------------|
| Simple power-law        | 1.66 ± 0.04| ...        | ...                 | ...         | ...                                    | 5.79                                                       | 114.9/123   |
| Broken power-law        | 1.66 ± 0.05| 2.40 ± 0.22| 0.82 ± 0.10         | ...         | ...                                    | 5.80                                                       | 111.2/121   (86%) |
| Power-law + blackbody   | 1.65 ± 0.05| ...        | 0.11 ± 0.03         | 3.63 ± 0.90 | ...                                    | 5.81                                                       | 111.4/121   (85%) |

Note. — Errors are quoted at the 90% confidence level for 1 parameter of interest ($\Delta \chi^2 = 2.71$).

a Photon index, related to the spectral index $\alpha$ (where $F \propto \nu^{-\alpha}$) by $\Gamma = 1 - \alpha$.

b High-energy photon index for the broken power-law model.

c Break energy for the broken power-law model.

d Temperature for the blackbody model.

e Number of hydrogen atoms.

in agreement with the intervals proposed by the SAX Cookbook. We fixed the intercalibration between PDS and MECS to the usual value, 0.85; the fit with a free normalization factor gives a slightly higher value (even if in the acceptable range), without considerable improvement in $\chi^2$.

3. SPECTRAL ENERGY DISTRIBUTIONS AND MODELS

3.1. 1997

Simultaneously with the BeppoSAX observations, 3C 279 was monitored in $\gamma$-rays by EGRET and in the optical at the Torino Observatory. The $\gamma$-ray data are reported in H01.

The $R$, $V$, and $B$-band magnitudes were obtained on 1997 January 11–18 at the 1.05 m REOSC telescope, equipped with a 1296 $\times$ 1152 pixel Astromed CCD camera with a 0.467 pixel$^{-1}$ image scale. Data were reduced with the locally developed ROBIN procedure, which includes bias subtraction, flat-field correction, and circular Gaussian fit. Magnitudes are reported in Table 3. A search in the University of Michigan Radio Astronomy Observatory (UMRAO) database provided radio data at 4.8 (1997 January 21–22), 8.0 (1997 January 24), and 14.5 GHz (1997 January 14).

In 1996 December 19 (only one month before the BeppoSAX pointings), 3C 279 was observed by ISOPHOT, the photometer on board the Infrared Space Observatory (ISO), as part of a program involving numerous active galactic nuclei (AGNs). The source was detected in seven bands, from 4.8 to 170 $\mu$m; results are reported in Haas et al. (1998).

All the above fluxes together with the deconvolved BeppoSAX 0.1–100 keV spectrum are shown in Figure 2. The X-ray spectrum is flat, while the connection with the EGRET $\gamma$-ray data indicates a steepening of the SED between the two ranges. The $\gamma$-ray flux is slightly higher than that measured in 1993, when the source was in a very low emission state (see the next section); the same occurs for the optical luminosity.

Finally, it is notable that the far-infrared peak observed by ISO dominates the bolometric luminosity. Integrating the measured fluxes, Haas et al. (1998) find $L_{IR} = 2 \times 10^{47}$

TABLE 3

| Date       | $R$          | $V$          | $B$          |
|------------|--------------|--------------|--------------|
| 1997 Jan 11... | 15.50 ± 0.03 | 15.93 ± 0.04 | ...          |
| 1997 Jan 12... | 15.46 ± 0.02 | 15.88 ± 0.03 | 16.31 ± 0.07 |
| 1997 Jan 13... | 15.37 ± 0.03 | 15.84 ± 0.04 | 16.37 ± 0.05 |
| 1997 Jan 14... | 15.50 ± 0.02 | ...          | ...          |
| 1997 Jan 15... | 15.48 ± 0.04 | 15.99 ± 0.05 | ...          |
| 1997 Jan 16... | 15.48 ± 0.02 | 15.95 ± 0.07 | ...          |
| 1997 Jan 17... | 15.49 ± 0.02 | 15.98 ± 0.03 | ...          |
| 1997 Jan 18... | 15.52 ± 0.02 | 16.01 ± 0.04 | 16.55 ± 0.05 |
| 1997 Jan 18... | 15.57 ± 0.02 | 15.98 ± 0.03 | ...          |
| 1997 Jan 18... | 15.50 ± 0.03 | 16.07 ± 0.04 | ...          |
| 1997 Jan 18... | 15.50 ± 0.04 | ...          | ...          |
ergs s$^{-1}$. This value is similar to that found for three other flat-spectrum radio quasars examined by the same authors; however, while in the other flat-spectrum radio quasars the infrared emission is a smooth continuation of the synchrotron spectrum, in the case of 3C 279 the IR spectrum shows a narrow peak suggestive of a thermal origin.

However, previous observations with IRAS in four bands from 12 to 100 $\mu$m (see Impey & Neugebauer 1988; Moshir 1990) yielded a 60 $\mu$m flux density and three upper limits lower than the fluxes measured by ISO, principally at 60 $\mu$m (a factor of $\sim$9). If this discrepancy is real (see Haas et al. 1998), the implied variability would not be consistent with thermal emission from a region of about 1 kpc.

Moreover, from the shape of the ultraviolet spectrum in the lowest state, one can derive an upper limit of $\sim 2 \times 10^{45}$ ergs s$^{-1}$ for the UV luminosity of a possible accretion disk in 3C 279 (Pian et al. 1999). Since in the case of 3C 279 the line of sight is at a small angle to the axis of the relativistic jet, which is presumably close to that of the putative accretion disk, it is difficult to suppose the existence of a hidden nuclear UV component with an intensity similar to that of the IR emission. Thus it is not easy to understand how the dust could be heated, unless the AGN underwent a long phase of higher activity in the past or a highly luminous starburst is taking place in this galaxy.

### 3.2. Multiepoch SEDs

One of the characteristic properties of blazars is the extreme variability, observed at all wavelengths but much more accentuated at high energies. Understanding this trait can provide important information about mechanisms operating in the inner regions of the source. Therefore, after collecting data provided from the campaign organized in 1997, we revisited several SEDs of 3C 279 obtained with simultaneous or quasi-simultaneous multiwavelength data, with the scope of comparing different states of emission. In the following, we briefly recapitulate basic information on the SEDs used: the first refers to the epoch of the $\gamma$-ray discovery of 3C 279 in 1991, and the other three are based...
on organized campaigns with wide multiwavelength coverage (1993 and 1996 preflare and flare).

1991.—The first detection of \(\gamma\)-ray emission dates from 1991 June 16–28: the flux measured by EGRET was very intense, with evidence of a flare on a timescale of days (Kniffen et al. 1993); a second observation (1991 October 3–17) revealed a lower flux level. A literature search provided quasi-

simultaneous data to the EGRET observations (see Hartman et al. 1996; Bonnell, Vestrand, & Stacy 1994) for assembling the SED shown in Figure 3 (top panel). IR data were obtained on 1991 June 16, and the optical spectrum is an average over the epoch of the \(\gamma\)-ray flare, while the UV observations date from 1991 July 27, without resorting to the correlation between UV and \(R\)-band fluxes applied in Hartman et al. (1996).

1993.—This first multiwavelength campaign organized after the discovery found 3C 279 in a low state: the emission had faded dramatically at all frequencies above \(10^{14}\) Hz, while the flux variations at radio to millimeter wavelengths were minor. To assemble the SED in Figure 3 (bottom panel), we used data from Maraschi et al. (1994), but differently from that work, the EGRET observation (having a 4 \(\sigma\) level) is taken as an upper limit.

1996.—Throughout this second multiwavelength campaign, 3C 279 was in a high state, similar to that of 1991; during the observation there was an extraordinary flare lasting 2–3 days, particularly intense in the \(\gamma\)-ray band. Following Wehrle et al. (1998), we divided the light curve in two parts, averaging the observed fluxes in the period January 24–28 preceding the flare, and in a 2 day window centered on the \(\gamma\)-ray peak. The resulting SEDs are shown in Figure 4.

4. INTERPRETATION

In order to reproduce the observed SEDs, we used a model with minimal assumptions. The emitting region is described as a homogeneous sphere with radius \(R\) endowed with a magnetic field \(B\) and moving with bulk Lorentz factor \(\Gamma\); the line of sight is at an angle \(\theta\) with respect to the jet axis, so that the Doppler factor \(\delta = 1/[\Gamma(1 - \beta \cos \theta)]\) is relevant for relating observed quantities with rest-frame quantities. The source is filled with relativistic electrons, whose energy spectrum is described by a broken power law between \(\gamma_{\text{min}}\) and \(\gamma_{\text{max}}\) that is determined by four parameters, the break energy \(\gamma_b(\gg 1)\), the normalization \(k\), and the spectral indices of the asymptotic power laws below and above the break, \(n_1 < 3\) and \(n_2 > 3\), respectively (see Tavecchio, Maraschi, & Ghisellini 1998):

\[
N(\gamma) = k\gamma^{-n_1} \left(1 + \frac{\gamma}{\gamma_b}\right)^{n_1 - n_2}.
\]

This form for the distribution function has been assumed in order to describe the curved shape of the SED. We used \(\gamma_{\text{min}} = 5 \times 10^4\) for all the states. The value of the minimum energy of the scattering electrons is uncertain. We assumed \(\gamma_{\text{min}} = 1\), as inferred in the case of other emission-line blazars from the lack of spectral breaks in the soft X-ray continuum (see Tavecchio et al. 2000).

Electrons emit via the synchrotron and inverse Compton mechanisms. At low frequencies, the synchrotron spectra are limited by the self-absorption frequency. Below that frequency, the model has the standard self-absorbed spectrum with slope 5/2. Additional emission components from regions farther out in the jet are necessary to account for the spectra at lower frequencies, as indeed expected if the flat radio spectra of blazars are due to the superposition of different self-absorbed components from different locations in the jet. The SEDs calculated here refer to the innermost emitting region.

**Fig. 4.—** Overall SEDs of 3C 279 dating back to 1996 January (preflare; top panel) and 1996 February (flare; bottom panel). Short-dashed, long-dashed, dot-short-dashed, and dotted curves show the synchrotron, external Compton, synchrotron self-Compton, and disk components, respectively (for details of the model, see the text). The solid line is a sum of all the contributions. Simultaneous data are from Wehrle et al. (1998).
The inverse Compton spectra have been calculated using the full Klein-Nishina cross section (Jones 1968; see also Blumenthal & Gould 1970) and taking into account the beaming of the external radiation in the blob frame, as pointed out in Dermer (1995). There the author uses a single power law as the electron distribution and a monochromatic external radiation. In our case, the flux calculation can only be made numerically because we use a more complex electron distribution.

We neglected the direct contribution of photons from the accretion disk since it is strongly redshifted in the comoving frame when the bulk Lorentz factor is large and the γ-ray emission occurs at a distance \( \geq 10^{17} \) cm (Sikora et al. 1994). The dominant contribution to the external radiation can be identified with that produced by the BLR via reflection/reprocessing of the disk emission. The spectrum of the BLR is described by a blackbody peaking at a frequency \( v_{\text{BLR}} = 10^{15} \) Hz with a luminosity \( L_{\text{BLR}} \) diluted in a spherical region with radius \( R_{\text{BLR}} \). For 3C 279, the BLR luminosity was estimated in Celotti, Padovani, & Ghisellini (1997) from the observed emission lines (see also Francis et al. 1991) as \( L_{\text{BLR}} = 6 \times 10^{44} \) ergs s\(^{-1}\). This value corresponds to \( \sim 30\% \) of the accretion disk luminosity estimated by Pian et al. (1999) from the UV observations during the 1993 campaign. Applying the model to the 1993 state, the one with lowest emission, we found that the best reproduction was obtained for an energy density \( u_{\text{BLR}} \sim 10^{-4} \) ergs cm\(^{-3}\); this corresponds to a BLR radius \( R_{\text{BLR}} = 4 \times 10^{18} \) cm, consistent with the value obtained from the \( R_{\text{BLR}}L_{\text{BLR}} \) relation found by Kaspi et al. (2000). This value was then kept fixed for all states.

We also estimated the possible contribution of the observed IR radiation. From the luminosity and temperature given by Haas et al. (1998), we derived the minimum radius of the emitting region \( R_{\text{min}} = (L_{\text{IR}}/4\pi T_{\text{IR}}^4)^{1/2} \sim 10^{20}-10^{21} \) cm and a maximum energy density \( u_{\text{IR}} \sim 10^{-8}-10^{-5} \) ergs cm\(^{-3}\), negligible with respect to the BLR energy density calculated above.

Finally, modeling the emission from blazars, it is common to adopt the relation \( \delta \sim \Gamma \), corresponding to an angle of view \( \theta = 1/\Gamma \). However, studying different states of the same object, we intended to allow variations of \( \Gamma \) and \( \delta \) but not of the angle of sight; so we fixed it to a value \( \theta = 3^\circ \), leaving the Lorentz factor \( \Gamma \) free to vary and computing the corresponding value of \( \delta \).

The computed models are shown together with the data in Figures 2, 3, and 4 with the different components (synchrotron, disk radiation, SSC, and EC), as well as their sum, plotted separately. In Figure 5 the models (sum of all the contributions) reproducing the SEDs of the different states are compared with each other.

We tried to reproduce the different levels by varying the smallest possible number of parameters. Our models are consistent with the observed variations being essentially due to the bulk Lorentz factor \( \Gamma \) (also in the short timescale flare observed in 1996); the parameters required are given in Table 4. The goodness of the choice of \( \gamma_{\text{min}} = 1 \) was verified a posteriori: considering all the states, we found that if \( \gamma_{\text{min}} > 5 \) the models cannot reproduce the hard X-ray/soft γ-ray data. The magnetic field is \( \lesssim 0.5 \) G in all states, while the size of the emitting region and the Doppler factor used allow variability timescales \( t_{\text{var}} = R/\gamma c \) from 1 to 2 days, consistent with the observations. We note that the small angle of view (\( \theta = 3^\circ \)) and the high bulk Lorentz factor (from 6 to 17) used involve relatively high super-

![Figure 5](attachment:image.png)

**Fig. 5.**—Comparison between the SEDs of 3C 279 in different levels: the lines reported are sums of all the components used to describe the emission observed (synchrotron radiation, SSC, EC, and disk emission).

| Date       | \( \Gamma \) | \( \delta^\circ \) | \( B \) (G) | \( \gamma_{\text{min}} \) (10\(^{-2}\)) | \( n_1 \) | \( n_2 \) | \( k \) (10\(^{3}\) cm\(^{-3}\)) |
|------------|-------------|-------------------|---------|-------------------------------|-------|-------|-----------------------------|
| 1991       | 13          | 17.8              | 0.6     | 5.5                           | 1.6   | 4.7   | 5                           |
| 1993       | 6           | 10.9              | 0.7     | 4.5                           | 1.6   | 4.4   | 5.6                         |
| 1996 preflare | 11       | 16.5              | 0.5     | 5                             | 1.6   | 4.7   | 5                           |
| 1996 flare | 17          | 19                | 0.5     | 4.9                           | 1.6   | 4.7   | 5.3                         |
| 1997       | 7           | 12.3              | 0.5     | 6.0                           | 1.6   | 4.2   | 4.5                         |

**Note.**—The BLR luminosity is \( L_{\text{BLR}} = 6 \times 10^{44} \) ergs s\(^{-1}\). We assume a blob with \( R = 5 \times 10^{18} \) cm in this radiation field diluted in a region with radius \( R_{\text{BLR}} = 4 \times 10^{18} \) cm. The electron distribution extends from \( \gamma_{\text{min}} = 1 \) to \( \gamma_{\text{max}} = 5 \times 10^4 \), and the angle of view is \( \theta = 3^\circ \). These values were kept fixed in all fits (see the text for more details).

* This is completely determined if \( \Gamma \) and \( \theta \) are fixed; therefore this is not a free parameter.
luminal speeds, from $\beta_{\text{app}} \sim 3$–4 in the low states to $\beta_{\text{app}} \sim 12$–15 in the high levels. Superluminal velocities observed in 3C 279 range from 3c–5c (Unwin et al. 1989; Carrara et al. 1993) to 4.8c–7.5c derived from a long-term high-frequency VLBI monitoring of six superluminal components in the relativistic jet in 3C 279 (see Wehrle et al. 2001). Higher velocities have also been measured in the past: Cotton et al. (1979) originally found a value of 15c (speeds have been expressed assuming $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$ and $q_0 = 0.1$). These velocities refer, however, to regions farther away along the jet, while our data concern the emission from much smaller scales. Thus the comparison, although interesting, can only be indicative. We would like to mention that in the internal-shock model, it is predicted that shells with high $\Gamma$ will slow down to an average value of $\Gamma$ farther out.

In the models above, the X-ray emission is attributed to the SSC mechanism, while the $\gamma$-ray emission is ascribed to the EC process; in this case, supposing a variation in the bulk Lorentz factor $\Gamma$, one expects that the relative change of the peak emission of these two components follows the relation $F_{\text{EC}} \propto F_{\text{SSC}}^{3/2}$ (see Ghisellini & Maraschi 1996). We searched for a correlation between X-ray and $\gamma$-ray fluxes in 3C 279 using all the available simultaneous measurements in the two bands derived from H01; in Figure 6 we plot $v_c F_v$ versus $v_c F_{\gamma X}$. The X-ray data are not completely homogeneous. When possible, we used the flux measured at 3 keV. Otherwise, we took the available flux at a slightly different energy ($\sim 2$ keV). For the EGRET data, $v_c$ is taken at 167 MeV (frequency at which observations for all the states are given in H01). In some cases, H01 gives two fluxes corresponding to energies of 121 and 208 MeV, respectively. In these cases we used an average flux. For all the measurements, the plotted errors are the maximum between the value provided and 5% of the flux in order to take into account intercalibration problems. The straight line, obtained with a fit that considered the errors in both ranges, has slope $1.49 \pm 0.13$, in good agreement with the expectation.

5. DISCUSSION AND CONCLUSIONS

We have analyzed the X-ray spectra of 3C 279 obtained from the BeppoSAX satellite in 1997 January. The result of our analysis is that the featureless X-ray continuum in the 2–100 keV energy band is well represented by a power law with $\alpha \sim 0.66$. The observations from BeppoSAX were part of an organized campaign also involving $\gamma$-ray and optical measurements; adding radio data from the UMRAO database and IR data from ISO, 1 month earlier than the high-energy observations, a quasi-simultaneous SED from radio to $\gamma$-rays was derived.

We also revisited the overall SEDs of four other different states of 3C 279 with wide simultaneous spectral coverage, from 1991 to 1997. We modeled the observed SEDs with the widely used homogeneous synchrotron/inverse Compton model, estimating the physical parameters in the emission region. This was done using the minimum possible number of free parameters.

The model used in this work (simpler than the one adopted in H01) is fully specified by eight parameters: the four parameters of the electron distribution, the magnetic field, the size of the emitting region, the bulk Lorentz factor, and the angle of view. In addition, the external radiation energy density and the typical frequency of the photons enter in the model. The latter is practically fixed at $v_{\text{esc}} \approx 10^{13}$ Hz, while the former has been inferred estimating the luminosity and the dimension of the BLR, so they cannot be considered free parameters. From an observed SED, we can in principle obtain six quantities, namely the synchrotron peak frequency and luminosity, the inverse Compton peak frequency and luminosity, and the spectral indices of the synchrotron component after the peak and of the inverse Compton component before the peak (connected to the indices of the electron distributions $n_2$ and $n_1$, respectively). In addition to these six quantities, the typical variability timescale can give an upper limit to the size of the source. Fixing the angle of view, the total number of observational constraints is equal to the number of parameters of the model that can therefore in principle be fully constrained (see Tavecchio et al. 2000). In the case of 3C 279, the main observational uncertainty is the position of the synchrotron peak, falling in the poorly covered far-IR (FIR) band. However, given the fact that we consider five states, we feel that within the model assumptions our parameter determination is robust.

We confirm that the bulk of the $\gamma$-ray (MeV–GeV) emission can be modeled as inverse Compton radiation produced by electrons in the jet, upscattering soft ambient photons reprocessed in the broad-line region, as originally proposed by Sikora et al. (1994); for a recent review of blazar models, see Sikora & Madejski 2001), while the X-ray continuum should be due to synchrotron self-Compton radiation. Notably, the relation between the $\gamma$-ray and X-ray fluxes of all the available simultaneous observations follows the relation expected under this hypothesis.

The most interesting result of our study is that the SEDs of the five different states considered here can be repre-

![Fig. 6—Gamma-ray vs. X-ray flux for different source states. For the former, we used fluxes at 167 MeV, while the latter was measured at 3 keV.

For several states, we have only a maximum and a minimum flux in the X-ray band. Data are from H01 (see this article for the references); we thought it right to use as errors in both the ranges the maximum between the values provided and 5% of the flux, in order to take intercalibration problems into account. The fit with a straight line provides a slope $1.49 \pm 0.13$, with $\chi^2 = 2.76$.](image-url)
duced by varying in a substantial way only one parameter, namely the bulk Lorentz factor $\Gamma$ of the emitting region, and considering all the other physical quantities (size, magnetic field, electron distribution) as almost constant. A significant variation of $\Gamma$ can be understood if the jet is energized by the injection of shells with initially different values of the bulk Lorentz factor, as proposed in the internal-shock model (see Spada et al. 2001; Ghisellini 1999). The collision between successive shells naturally predicts the production of a new shell with an intermediate $\Gamma$ on short timescales, as necessary in the case of the 1996 flare.

Other causes of variability may coexist with the above, as it is very possible to reproduce the observed variability varying more than one parameter. Even then, however, it is not possible to reproduce the variability behavior without varying $\Gamma$ (H01). In particular, we cannot exclude that the peaks of the main emission components shift to higher energies in brighter states. This is in fact suggested by the hardening of the $\gamma$-ray spectrum. However, the position of the synchrotron peak in this source, as well as in many emission-line blazars, is difficult to constrain, since it falls in the FIR band, in which observations are difficult.

Even taking into account the above uncertainties, it seems that the variability behavior of 3C 279 differs from that of Mrk 501, one of the best studied and most "extreme" or "high energy peaked" BL Lac objects in the spectral sequence discussed by Fossati et al. (1998; see Costamante et al. 2001). In the latter case, the large spectral variability observed in X-rays on short and long timescales, causing a substantial shift in the peak of the synchrotron emission, appears to be mainly due to the variation of the energy of electrons emitting at the peak (those at $\gamma_b$, Tavecchio et al. 2001), presumably because of a change in the acceleration process not associated with a significant change in $\Gamma$. In fact, the emission of Mrk 501 in the soft X-ray band varies much less than in the medium–hard band, implying strong intrinsic spectral changes and small, if any, variations in $\Gamma$, at least within a homogeneous model.

These issues are clearly important for a physical understanding of the variability of blazars that could be driven by somewhat different processes in different "types" of blazars (emission-line blazars vs. BL Lac objects, or high luminosity vs. low luminosity; see Ghisellini et al. 1998; Ghisellini & Celotti 2001). Simultaneous access to X-ray, FIR, and $\gamma$-ray plus ground-based facilities, as will be possible in the next few years, will allow us to test new ideas in this field.

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