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OSSE Observations of 3C 273

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ABSTRACT

We report results of multiple observations of the quasar 3C 273 with the Oriented Scintillation Spectrometer Experiment (OSSE) instrument on the *Compton* Gamma Ray Observatory. These observations span the period from 1991 June through 1993 January and represent the most sensitive observations to date in low-energy gamma rays. The source was detected at historically weak 100 keV fluxes compared with previous measurements. Variability by factors of ~ 3 on time scales of ≈ 2 months was observed in the energy band 50 keV – 150 keV. The data are well described by a single power law with a photon number index , $= 1.7 \pm 0.1$. No significant change of , was observed during changes in intensity. Thermal models do not provide acceptable fits to the data. When the OSSE data are combined with contemporaneous measurements by COMPTEL and EGRET, the spectrum is seen to break at an energy of $1.0^{+0.9}_{-0.4}$ MeV to a softer power law with Δ, $= 0.7^{+0.06}_{-0.11}$, forming a power law with , $= 2.4$ between ~ 1 MeV and several GeV.

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1. Introduction

3C 273 is one of the nearest quasars ($z = 0.158$), the second quasar discovered (after 3C 48), and the first extragalactic source detected at photon energies $E \approx 100$ MeV (Swanenburg et al. 1978). *HEAO-1* X-ray observations of 3C 273 showed a hard power-law spectrum with photon spectral index , $= 1.41 \pm 0.02$ in the 2-60 keV range (Bradt et al. 1979; Worrall et al. 1979), steepening to , $= 1.67 \pm 0.14$ in the 13-120 keV range (Primini et al. 1979). The hardness of the X-ray spectrum between ~ 2 and 35 keV was confirmed by *EXOSAT* and *Ginga* observations (Turner et al. 1990), which also demonstrated the existence of a soft X-ray excess at $E \lesssim 1$ keV. The *Ginga-EXOSAT* observations showed factor-of-2 variability on time scales of weeks, and further showed that variations in the soft X-ray excess were uncorrelated with hard X-ray emission, implying that the soft and hard X-rays originate from separate emission regions. *COS-B* gamma-ray observations between 50 and 800 MeV indicated further spectral steepening to , $= 2.6 \pm 0.4$ (Bignami et al. 1981; Hermsen et al. 1981). Several multi-wavelength campaigns to monitor 3C 273 from radio to X-rays have been undertaken (Courvoisier et al. 1987, Courvoisier et al. 1990). These campaigns reported temporal correlations between the radio and UV emissions, but no correlations were reported between the X-ray and other wavelength ranges.

The launch of the *Compton* Gamma Ray Observatory (CGRO) has provided greatly enhanced capability in the energy range above 30 keV and has extended the multi-wavelength monitoring of 3C 273 to high energies (Lichti et al. 1994). The CGRO data show 3C 273 to be a member of the gamma-ray blazar class of AGNs discovered with EGRET (Fichtel et al. 1994) at $E > 30$ MeV. These objects are identified with core-dominant radio sources such as flat-spectrum quasars and BL Lac objects. Many of these sources, including 3C 273 (e.g., Davis, Unwin, & Muxlow 1991), exhibit apparent transverse superluminal motion and are highly variable from the radio through the X-ray regime. Such phenomena are thought to be the result of relativistic plasma outflows from radio jets of AGNs which are oriented so that the axis of the radio jet is nearly aligned in the direction of the observer.

In this paper we report on observations of 3C 273 made with the Oriented Scintillation Spectrometer Experiment (OSSE) on CGRO during the first two years of the mission. Eight separate observations, varying in duration from approximately one to two weeks, were performed between 1991 June 15 and 1993 Jan 12. These data provide the most sensitive soft gamma-ray observations of 3C 273 to date and, particularly in conjunction with the coordinated data from COMPTEL and EGRET, provide important constraints on theoretical models of the high energy emission from this source. In Section 2 we describe the OSSE instrument and the observations of 3C 273, in Section 3 we present the analysis of the observations, and we discuss the results in Section 4.

2. Observations

The Oriented Scintillation Spectrometer Experiment (OSSE), one of four experiments on NASA's *Compton* Gamma Ray Observatory (CGRO) satellite, observes gamma rays in the $0.05-10$ MeV range. OSSE consists of four identical detector systems with independent, single-axis orientation controls which provide an orientation range of 192 degrees. Each detector contains a NaI(Tl)–CsI(Na) phoswich which is actively shielded by an annulus of NaI(Tl) scintillation crystals. A tungsten slat collimator defines a $3.8^\circ \times 11.4^\circ$ full width at half maximum (FWHM) gamma-ray aperture for the phoswich detector. The total aperture area of the four detectors is 2620 cm^2, with an effective photopeak area at 511 keV of $\sim$ 2000 cm^2. These characteristics result in an OSSE 3σ continuum sensitivity of $\sim 1.2 \times 10^{-3}$ photons cm^{-2} s^{-1} MeV^{-1} at 100 keV for a standard observing time of 5×10^5 seconds. A more detailed description of OSSE, its performance and spectral data analysis procedures can be found in Johnson et al. (1993).

Table 1: OSSE Observations of 3C 273

CGRO View Period	Observation Dates	Average Flux[a] 0.05 – 0.15 MeV	Live Time (10^5 sec)
3	1991 Jun. 15 - 28	17.5 ± 0.5	8.1
8	1991 Aug. 22 - Sep. 5	5.7 ± 0.8	3.8
11	1991 Oct. 3 - 17	3.6 ± 0.6	5.7
36.5	1992 Aug. 12 - 15	16.0 ± 2.2	0.3
39	1992 Sep. 8 - 12	18.1 ± 1.4	0.8
204 - 206	1992 Dec. 22 - 1993 Jan. 12	7.9 ± 1.0	1.8

[a] $\times 10^{-3}$ photons $cm^{-2}s^{-1}MeV^{-1}$

OSSE observed 3C 273 in the energy range 50 keV$-$10 MeV during eight observing periods spanning 1991 June 15 through 1993 Jan. 12. These observations are summarized in Table 2.. The 1991 observations of 3C 273 were also designed to observe the Type Ia supernova SN 1991T, which was discovered on 1991 April 13 (Waagen & Knight 1991) in the spiral galaxy, NGC 4527, on the edge of the Virgo cluster. The OSSE observing sequence simultaneously viewed both 3C 273 and SN 1991T which are separated by 1.4°. The objective of the observation of SN 1991T was the detection of the emission lines of ^{56}Co radioactive decay. As discussed in Leising et al. (1994), the observation resulted in upper limits for the principal lines at 0.847 MeV and 1.238 MeV. Consequently the contribution of SN 1991T to the continuum emission from the field of view is expected to be insignificant.

In the 1991 June and 1991 August observations (viewing periods (VPs) 3 and 8, respectively), 3C 273 was offset from the center of the detector field-of-view by 0.7° in the scan direction (3.8° FWHM collimator response) and by 0.7° in the cross-scan direction (11.4° FWHM collimator response), resulting in $\sim$ 75% of maximum response to the source. In 1991 October the source was observed at scan and cross-scan angles of 0.4° and 0.0°, respectively. In all observations, background fields were selected at least 4.5° removed from 3C 273 in the scan direction. Fields on each side of the target, in the scan direction, were used in background estimations as discussed in Johnson et al. (1993). The background field selection (scan angle) was designed to avoid the potentially confusing sources 3C 279 (10.9° from 3C 273) and NGC 4593 (7.8° from 3C 273).

Data screening was performed to select only the highest quality data of both source and background observations. Background estimation was achieved by performing a quadratic fit to three or four (where possible) contiguous two-minute background accumulations of satisfactory data quality collected immediately before or after each two-minute source accumulation. These background estimates were then subtracted from the associated source accumulation to form two-minute source-field residuals. These residuals were further screened for environmental effects or transient phenomena. These screened residuals were then summed into daily average residual fluxes and finally into spectra averaged over the entire observation interval. Table 2. gives the total accumulated on-source live time for each observation in units of detector-seconds. Comparable times were spent on background observations. The variations in live time can be attributed to the durations of the obseravations (3 days – 2 weeks), the reduction in data acquisition caused by the failure of the GRO tape recorders (50% – 100% data recovery), the number of detectors used in the observation (2 or 4), and the sharing of the viewing sequence with more than one target. The table also shows the detected average flux in the 50 – 150 keV energy band for each period as an indication of the source strength. The wide variation in relative uncertainties of these measured fluxes is attributable to the aforementioned variation in live times for the viewing periods rather than any degradation in OSSE performance.

3. Analysis

3.1. Temporal Analysis

The average flux from 3C 273 in the 50 – 150 keV band as measured with OSSE is shown in Figure 1. The data from the eight observing periods have been averaged into 3- to 4-day intervals. Flux variations between viewing periods 3 and 8 (days 176 – 250) indicate variability by as much as a factor of three on time scales of $\approx$ 2 months. The lower flux measured in VP11 ($\sim$ day 290) indicates variability by a factor of ≈ 4 on 3 – 4 month time scales. In the June 1991 viewing period, when 3C 273 was at its brightest state observed by OSSE, the daily average flux in the 50 – 150 keV energy band was not consistent with a constant flux throughout this viewing period (χ^2 probability $\sim 6 \times 10^{-3}$). Day-to-day variations as large as 25% are seen, suggesting source variability over the two week period at $> 2.5\sigma$ significance. In the later observations when

3C 273 was observed at lower flux levels, we find no evidence for statistically significant day-to-day variability. Even during the return to increased emission in 1992 Aug. – Sep., 3C 273 shows no significant short term variability. However, the sensitivity per day of those observations was worse than that during the 1991 June period by a factor of ~ 2. Contemporaneous observations with the CGRO COMPTEL and EGRET experiments were performed during VP 3 (Lichti et al. 1994), VP 11, and VP 204 – 206, and are discussed in more detail below.

3.2. Spectral Analysis

We have organized the eight observations of 3C 273 into four time-averaged spectra covering contiguous time periods of no more than two months and being generally consistent with the same flux state. (The up to 25% variations seen in the 1991 June period indicated no statistically significant change in spectral shape, so that these variations were averaged for the period.) These four time intervals are (1) 1991 June, (2) 1991 Aug. – Oct. (3) 1992 Aug. – Sep., and (4) 1992 Dec. – 1993 Jan. Spectral analysis of the individual viewing periods gives results consistent with their associated multi-period average. Significant flux between 50 keV and $\sim$ 500 keV was measured in each of the four spectra. Spectral fitting was performed in the interval 50 keV – 1 MeV. The fitting procedure consisted of folding model photon spectra through the OSSE response matrix and adjusting the model parameters to minimize, through a χ^2 test, the deviations between the model count spectrum and the observed count spectrum. Except possibly for the observations in interval (2), the spectra are reasonably well described by simple power-law models as indicated in Table 3.2.. Generally, models with high energy cutoffs such as simple exponential and thermal Bremsstrahlung models did not provide acceptable fits ($\chi^2_\nu > 2.3$). Models consisting of a power law $\times$ exponential cutoff provided acceptable fits by placing the cutoff energy well above the OSSE energy range, thus providing a simple power law form in the OSSE energy band. However, in the low intensity state observed in 1991 Aug. – Oct. a simple exponential model with e-folding energy of $\sim$ 100 keV provided a slightly better fit than the power law model. The spectra and best fit power law models are shown in Figure 2.

There is a suggestion in the 1991 June observation (VP3) for a two-component spectrum. When the data below 0.1 MeV are excluded from the fit, the best fit power-law index changes from 1.7 to 1.5 (see Table 2). While the change is only marginally significant, it may indicate a contribution to the observed OSSE flux from GRS 1227+025, which was identified as a hard X-ray source with SIGMA (Jourdain et al. 1992), and is separated from 3C 273 by only ≈ 0.25 deg. Significant hard X-ray emission near 50 keV from GRS 1227+025, comparable in intensity with the 50 keV flux from 3C 273, was observed in 1990 Nov. SIGMA observations (Bassani et al. 1991). The source was not detected by them in 1990 June and July observations. They report a soft power law spectrum for GRS 1227+025 with , $= 3.0^{+1.3}_{-0.9}$. In subsequent observations during 1991 May – Jun, they report a possible 3σ detection of the source at approximately 40% of their discovery intensity (Bassani et al. 1993). A second fit to all the OSSE data was therefore performed using a model consisting of two power law components. One power law was fixed at the index $\Gamma = 1.5$ found above 0.1 MeV. The best fit two power law model resulted in a second power law with index of $3.4^{+2.1}_{-1.4}$ and 100 keV flux of $1.5^{+4.0}_{-1.2} \times 10^{-3}$ photons $cm^{-2}s^{-1}MeV^{-1}$. While a χ^2 test indicates a better fit for this model, the improvement is not significant as measured by an F-test. If the association of a second power law component with GRS 1227+025 is correct, however, then ~ 18% of the flux observed by OSSE in the 50 – 150 keV band could be attributed to that source and the flux observed by OSSE is ~ 20% of the peak flux reported by SIGMA during 1990 November observations. In the subsequent OSSE observations of 3C 273, however, there is no evidence for a softer low energy component in the observed spectra. We can not exclude the possibility of a contribution from GRS 1227+025 to the observed flux during VP3 (or from any of the observations); however, the possible contribution of a soft source such as GRS 1227+025 to the VP3 observed flux does not significantly alter the interpretation of the spectrum from 3C 273.

Table 2: Spectral Fit Summary

View Period	Flux[a] @ 100 keV	Power Law Index	$\chi^2_{\rm dof}$ (dof)	L_{46}(0.05 -1)[b]	$M_{8,min}$[c]	$\ell_{3\,day}$[d]
3	13.5 ± 0.5	1.7 ± 0.1	0.89 (23)	4.4	3.5	153
3[e]	12.1 ± 0.9	1.5 ± 0.1	0.80 (16)	4.9	3.9	171
8 + 11	3.8 ± 0.4	1.6 ± 0.2	2.15 (23)	1.4	1.1	49
36.5 + 39	13.6 ± 1.1	1.8 ± 0.2	0.88 (22)	4.0	3.2	139
204 – 206	6.6 ± 1.0	1.7 ± 0.3	1.21 (22)	2.1	1.7	73

[a] $\times 10^{-3}$photons $cm^{-2}s^{-1}MeV^{-1}$

[b] Luminosity in the 0.05 – 1 MeV range in units of 10^{46} ergs/s

[c] Minimum black hole mass in units of 10^8 $M_\odot$ with $\eta \approx 1$, see text

[d] Compactness, assuming 3-day variability

[e] fitting E > 100 keV

Figure 3 shows the OSSE spectra from 1991 June (VP3) and 1991 Aug. – Sep. along with previous X-ray and soft gamma-ray observations. As can be seen, the OSSE observations of 3C 273 have detected the source at an intensity much weaker than previous observations at $E > 50$ keV. The hard X-ray observations from EXOSAT and GINGA, also shown in Figure 3, are fit with power laws with index $\Gamma \sim 1.5$ (Turner et al. 1990). They report 2 – 10 keV flux variability by a factor of 2 on weekly time scales and small, but significant, variations in the power law index which are not correlated with flux amplitude. The OSSE observations indicate a slightly softer spectrum with no significant variation in power law index during a change in flux amplitude by a factor of 3 on time scales of months. The OSSE spectrum in June of 1991 extends to ~ 1 MeV without break. However, as seen in Figure 4, when the OSSE results are combined with the measurements of COMPTEL and EGRET, there is a significant break in the spectrum from , = 1.7 in the OSSE energy range to an index of , = 2.4 reported by EGRET (Montigny et al. 1993). The lower intensity of 3C 273 measured with OSSE apparently extends to higher energies, insofar as the reported EGRET flux above 100 MeV (Montigny et al. 1993) is approximately half of the COS-B intensity measured in 1978 (Bignami et al. 1981).

A fit to the contemporaneous VP3 OSSE, COMPTEL and EGRET data using a broken power law model requires a break at $E = 0.98^{+0.94}_{-0.37}$ MeV. The best fit for the broken power law model has low-energy spectral index , $= 1.7 \pm 0.1$ and a change in index between the low and high-energy power law fits of Δ, $= 0.7^{+0.06}_{-0.11}$. These uncertainties represent the 68% confidence interval for joint variation of the lower and upper indices and the break energy ($\Delta\chi^2 = 3.5$). Figure 4 also shows the data from contemporaneous VP11 observations in 1991 October when 3C 273 was not detectable by EGRET and only an upper limit was measured (Fichtel et al. 1994).

4. Discussion

Observations of AGNs indicate significantly different spectral characteristics for Seyfert AGNs and blazars (for reviews, see Lawrence 1987; Antonucci 1993; and Dermer & Gehrels 1994 for a gamma-ray perspective). These differences are probably due to the relative importance of quasi-isotropic accretion-disk radiation and beamed nonthermal jet radiation. Although 3C 273 is usually classified as a blazar due to observations of an optical (e.g., Thomson, Mackay, & Wright 1993) and radio (e.g., Davis et al. 1991) jet and the presence of a compact, flat spectrum radio core from which emerge components exhibiting apparent superluminal motion, it is unusual in having a UV "blue bump" luminosity which equals or even dominates the gamma-ray luminosity, in contrast to many of the other gamma-ray blazars. This UV excess has been interpreted in terms of the emission from an optically thick accretion disk (e.g., Shields 1978). Soft gamma-ray observations can provide particularly useful tests to determine if the high-energy emission from 3C 273 is beamed or isotropically emitted, because observations in the 50 keV - 10 MeV range permit derivation of strong beaming and gamma-ray transparency constraints.

3C 273 displays a hard spectrum in X rays with spectral index , $\approx 1.4 - 1.5$, with apparent softening in the OSSE energy range to a spectrum with , ≈ 1.7. The spectrum of 3C 273 measured with OSSE extends to ~ 1 MeV, above which the photon flux falls below the OSSE sensitivity limits. Contemporaneous OSSE, COMPTEL, and EGRET measurements in 1991 June (VP3) require additional, significant spectral softening at $E \sim 1$ MeV to a power law with , ≈ 2.4 at $E > 100$ MeV (Lichti et al. 1994). The shape of this softening in the energy band from $\sim 0.5 - 50$ MeV is not well determined due to the significance of the measurements in that band. However, the measurements are well described by a power law which breaks by Δ, ≈ 0.7 at $E \approx 1$ MeV. By contrast, the Ginga X-ray spectra of Seyfert AGNs (Pounds et al. 1990, Nandra & Pounds 1994) are described by intrinsic power laws with , $\sim 1.9 - 2.0$ and a reprocessed component due to Compton reflection (Lightman & White 1988). The reflection component hardens the intrinsic power law to , ~ 1.7 as seen by HEAO–1 and EXOSAT (Rothschild et al. 1983, Turner & Pounds 1989) and softens it to the , ~ 2.2 seen by OSSE for an average of 15 Seyferts at energies above 50 keV (Johnson et al. 1994). Comparison of Ginga and OSSE spectra for a set of 9 Seyferts (Zdziarski et al. 1995) additionally provides evidence for a high energy cutoff to the power law modeled as exponential with e-folding energy $\sim 0.4 - 0.6$ MeV. Strong spectral softenings are also implied for Seyfert 1 AGNs between ≈ 0.1 and 50 MeV by the lack of EGRET detections (Lin et al. 1993). As indicated in §3, the OSSE observations of 3C 273 can be well fitted by such models of an exponentially cutoff power law and reflection by moving the cutoff to beyond the OSSE energy range ($E_c > 10$ MeV). The best fit has no reflected component, however the 95% confidence interval does not provide a significant limit. When the contemporaneous COMPTEL and EGRET data are combined with the OSSE data, no acceptable fit can be found for an exponentially cutoff power law ($\chi^2_\nu > 3$).

X-ray spectra from Seyfert AGN as hard as 3C 273's have been observed. Zdziarski et al. (1995) report from Ginga/OSSE comparisions that radio loud Seyferts have harder spectra, , ~ 1.7, and that Seyfert 2 AGN may be harder than , ~ 1.9 but more strongly cutoff. NGC 4151, a Seyfert 1.5, has X-ray spectrum with , ≈ 1.5 (Yaqoob et al. 1993) but OSSE observations indicate that the spectrum is clearly thermal, with kT ~ 40 keV (Maisack et al. 1993), unlike that of 3C 273. Thus it appears that the high energy emission of 3C 273 is inconsistent with the spectral characteristics of typical Seyfert AGNs.

The spectrum of 3C 273 is also harder than that of the radio galaxy Centaurus A, which shows a spectral cutoff above several hundred keV and no evidence for emission in the EGRET energy range (Kinzer et al. 1994; Fichtel et al. 1994). The spectrum of 3C 273 is more characteristic of gamma-ray blazars, which display spectral indices at $E > 100$ MeV ranging from $1.5 \lesssim$, $\lesssim 2.6$. Although the > 100 MeV spectrum of 3C 273 is softer than the typical gamma-ray blazar, it is not unusual: 5 of the 17 gamma-ray blazars with measured > 100 MeV spectral indices have displayed spectra as soft or softer than , $= 2.4$ (Fichtel et al. 1994; Montigny et al. 1994). However, the bulk of the high-energy luminosity from 3C 273 is emitted near 1 MeV rather than at higher energies, as is the case for gamma-ray blazars such as 3C 279 (Maraschi et al. 1994) and 1633+382 (Mattox et al. 1994) which show peaks in νF_ν at $E \gtrsim 30$ MeV during 1991 June and $E \gtrsim 100$ MeV during 1991 September, respectively. But gamma-ray blazars with "soft"-spectra (, > 2) in the EGRET energy range, such as CTA 102, PKS 0528+134, and QSO 2251+158, have peaks in νF_ν between ~ 1 and 10 MeV (McNaron-Brown et al. 1994, 1995), so that the high-energy spectral shape of 3C 273 is indeed typical of soft-spectrum gamma-ray blazars.

We now consider gamma-ray arguments which would provide strong evidence for beaming and, thus, support the blazar interpretation for the origin of the high-energy emission from 3C 273. The first (Elliot & Shapiro 1974) considers the minimum black hole mass for Eddington-limited accretion derived for assumed isotropic gamma-ray luminosity and the characteristic size determined from observed variability time scale. The characteristic size places an upper bound on the mass assuming this scale is approximately the Schwarzschild radius. This relation implies that if the photon compactness

$$\ell \equiv \frac{L}{R}\,\frac{\sigma_T}{m_e c^3} \cong \frac{L}{(c\Delta t_{obs})\;3.7\times 10^{28}\ \mathrm{ergs\ s^{-1}\ cm^{-1}}} \cong \frac{100L_{46}}{(\Delta t_{obs}/\mathrm{days})} \gtrsim 10^4\ , \tag{1}$$

then beaming is required. Here we assume energy generation within a few Schwarzschild radii. Equation (1) only applies in the small redshift limit ($z = 0.158 \ll 1$ for 3C 273). In Table 2 we give the gamma-ray luminosities of 3C 273 in the energy range 0.05 – 1 MeV measured at the different viewing intervals listed in Table 2, assuming that the radiation is emitted into 4π steradians (for calculations of luminosity, we keep redshift corrections). The luminosities are in the range $\sim 2-5\times 10^{46}$ ergs s^{-1}. We also give the minimum black hole mass for Eddington-limited accretion in units of M_8 Solar masses, where the factor $\eta \sim 1$ accounts for the bolometric correction to high-energy radiation outside the OSSE range and the reduction in the radiation force due to Klein-Nishina effects. Finally, we give the compactness calculated from Equation (1) for a 3-day variability time scale. The compactness for a 2 month time scale are smaller by a factor of 20. Even for the 3-day variability time scale, the inferred values of ℓ are nearly two orders of magnitude smaller than necessary to require beaming, so these arguments do not provide a compelling case for beaming.

The second test examines the optical depth for photon-photon pair production and the resultant spectrum. This gamma-ray transparency argument indicates that, in the absence of a strong pair annihilation feature in the OSSE band, the assumption that the emission in the OSSE energy range is isotropically radiated from a source at rest in the cosmological frame is incompatible with the detection of gamma rays with COMPTEL. For this argument, we must assume that the gamma rays detected in the OSSE and COMPTEL energy ranges originate from the same emission region. Evidence in favor of this assumption is the apparent correlation in the decrease in flux observed late in 1991 in the OSSE and EGRET regimes (see Figure 4) which bound the COMPTEL energy range.

The pair-production optical depth for a photon with dimensionless energy $\epsilon_1 = E_1/m_e c^2$ interacting with a power law photon distribution is given by

$$\tau_{\gamma\gamma}(\epsilon_1) \cong R\int_{2/\epsilon_1}^{\infty} d\epsilon\ \sigma_{\gamma\gamma}(\epsilon_1,\epsilon)\ n_{ph}(\epsilon), \tag{2}$$

where $R \cong c\Delta t_{obs}$ is the size scale of the emission region, $\sigma_{\gamma\gamma}(\epsilon_1,\epsilon) \approx \frac{1}{3}\sigma_T\epsilon\delta(\epsilon-2/\epsilon_1)$ is the photon-photon pair production cross section, and the mean photon spectral density in the emission region is denoted by $n_{ph}(\epsilon) \cong d^2\Phi(\epsilon)/R^2c$ (Dermer & Schlickeiser 1994; for a more detailed treatment with redshift corrections, see McNaron-Brown et al. 1995). Here $d \cong 650h^{-1}$ Mpc is the distance to 3C 273 with Hubble constant $H_0 = 75h$ km s^{-1} Mpc^{-1}. Writing the photon flux observed in the OSSE range as $\Phi(E) = \Phi_0(E/0.1)^{-\Gamma}$, where Φ_0 is the flux at $E = 0.1$ MeV given in Table 2, we obtain

$$\tau_{\gamma\gamma}(\epsilon_1) \cong \frac{2}{3}\,\frac{d^2\sigma_T}{c^2\Delta t_{obs}}\,\frac{0.511}{\epsilon_1}\,\Phi_0(\frac{2\cdot 5.11}{\epsilon_1})^{-\Gamma}, \qquad (3)$$

Equation (3) applies to photons with 1 MeV $\lesssim E_1 \lesssim$ 10 MeV due to the threshold condition and limits on detection in the OSSE energy range.

Substituting $\Phi_0 = 13.5 \times 10^{-3}$ photons cm^{-2} s^{-1} MeV^{-1} and , $= 1.7$ for the OSSE measurements in VP3, we find that $\tau_{\gamma\gamma} \approx \epsilon_1^{0.7}/h^2$ for a three-day variability time scale, as inferred from observations during this viewing period (see Table 2 and Fig. 1). This implies that $\tau_{\gamma\gamma} \approx 1.6$ for a 1 MeV gamma ray and $\tau_{\gamma\gamma} \approx 10$ for a 10 MeV gamma ray. The detection of gamma rays with COMPTEL at several MeV is inconsistent with this attenuation unless the intrinsic source spectrum is very hard, in which case the the produced electrons and positrons would produce an annihilation feature with bolometric luminosity comparable to the continuum luminosity.

From the sum of all OSSE data we can place a 99% confidence limit of 3.4×10^{-5} photons cm^{-2} s^{-1} to the steady emission of a narrow feature from the annihilation e^+–e^- pairs at $511/(1+z)$ keV = 441 keV. At this energy the detector resolution is 9.5%. This upper limit can be compared with the 2σ upper limit from SIGMA of $\approx 1.5 \times 10^{-3}$ photons cm^{-2} s^{-1} (Bassani et al. 1992) and the HEAO-3 2σ upper limit of $\approx 2 \times 10^{-4}$ photons cm^{-2} s^{-1} (Wheaton et al. 1987). The OSSE upper limit represents a level of annihilation luminosity which is $< 10\%$ of the continuum luminosity. Thus the assumption that the source is stationary leads to large pair-production optical depths and the production of electron-positron pairs whose annihilation is not observed with OSSE. The upper limit to the annihilation feature also severely constrains nonthermal pair cascade models (Lightman & Zdziarski 1987, Zdziarski, Coppi & Lamb 1990) which have been applied to the high energy emission of AGN. In such models, soft UV photons (possibly from the accretion disk) are Compton-upscattered by a distribution of relativistic electrons. The observed high energy spectrum depends on the luminosities of the soft photon source and nonthermal source, the energy extent of the nonthermal source, and and the opacity to secondary pair creation by photon-photon interactions. Even for the compactnesses based on 2-month variability (Table 2, $\sim \ell_{3\,day}/20$), a detectable annihilation feature is expected. However, the best fit of this model to the combined OSSE, COMPTEL and EGRET data is not very good ($\chi^2_\nu = 1.9$).

If the hard X-rays and soft gamma rays are beamed jet radiation, then OSSE observations, in conjunction with other contemporaneous observations, can be used to test spectral predictions of current models for gamma-ray blazars. The magnitude of the spectral softening between the OSSE energy range and the EGRET energy range is given by Δ, $= 0.7^{+0.06}_{-0.11}$. Compton cooling models (Dermer & Schlickeiser 1993; Sikora, Begelman, & Rees 1994) predict that Δ, $= 0.5$, so that the OSSE/EGRET data present a weak conflict with these models at the 2σ level. A stronger conflict is found for 3C 273 when contemporaneous Ginga data are included (Lichti et al. 1994). A spectral softening with Δ, > 0.5 is also implied by the OSSE data for PKS 0528+134 (McNaron-Brown et al. 1995), another gamma-ray blazar, so present homogeneous, time-integrated Compton cooling models for gamma-ray jet emission are in conflict with observations. Compton models with the injection of mono-energetic rather than power-law electron spectra (e.g., Melia & Königl 1989; Protheroe, Mastichiadis, & Dermer 1992) can produce $\Delta, > 0.5$, but cannot produce an X-ray spectrum harder than $, = 1.5$, which may be in conflict with some measurements of the 2-10 keV X-ray spectrum (see Section 1).

The combined spectrum of 3C 273 shown in Figure 4 indicates that its peak luminosity occurs at $\approx 1 - 2$ MeV. If positrons are annihilating in the comoving jet frame, we could expect a broadened, blueshifted annihilation line in this energy range. The identification of such a feature would be particularly important to the interpretation of the $2 - 3$ MeV feature in the diffuse background radiation spectrum. However, two considerations argue against this possibility. First, the power output from most blazars peaks at higher energies and, although the detector sensitivity in this energy range is only adequate to detect a few AGNs (see also Schönfelder 1994), there have been no indications of annihilation features in the spectra of other gamma-ray blazars. Second, model calculations for the gamma-ray background based on assumptions about the radio/gamma-ray emissivity conclude that there are not enough blazars to account for the $\gg$ 1 MeV background (Salamon & Stecker 1994). Because of its relative proximity and brightness, it is nevertheless important to continue to search for line features in the spectrum of 3C 273 which would provide valuable information about the composition of emitting particles in gamma-ray jets.

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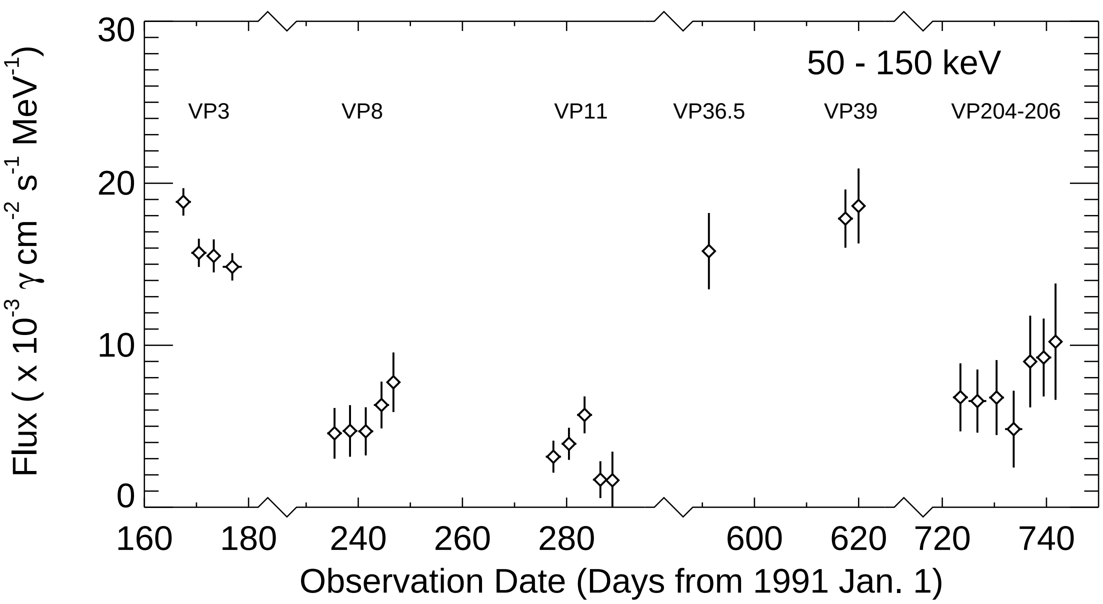

Fig. 1.— The time-averaged flux in the 50 – 150 keV band from 3C 273 observed with OSSE in eight observing periods from 1991 Jun 15 thru 1993 Jan 12. Each data point represents the average flux for a contiguous 3 – 4 day period.

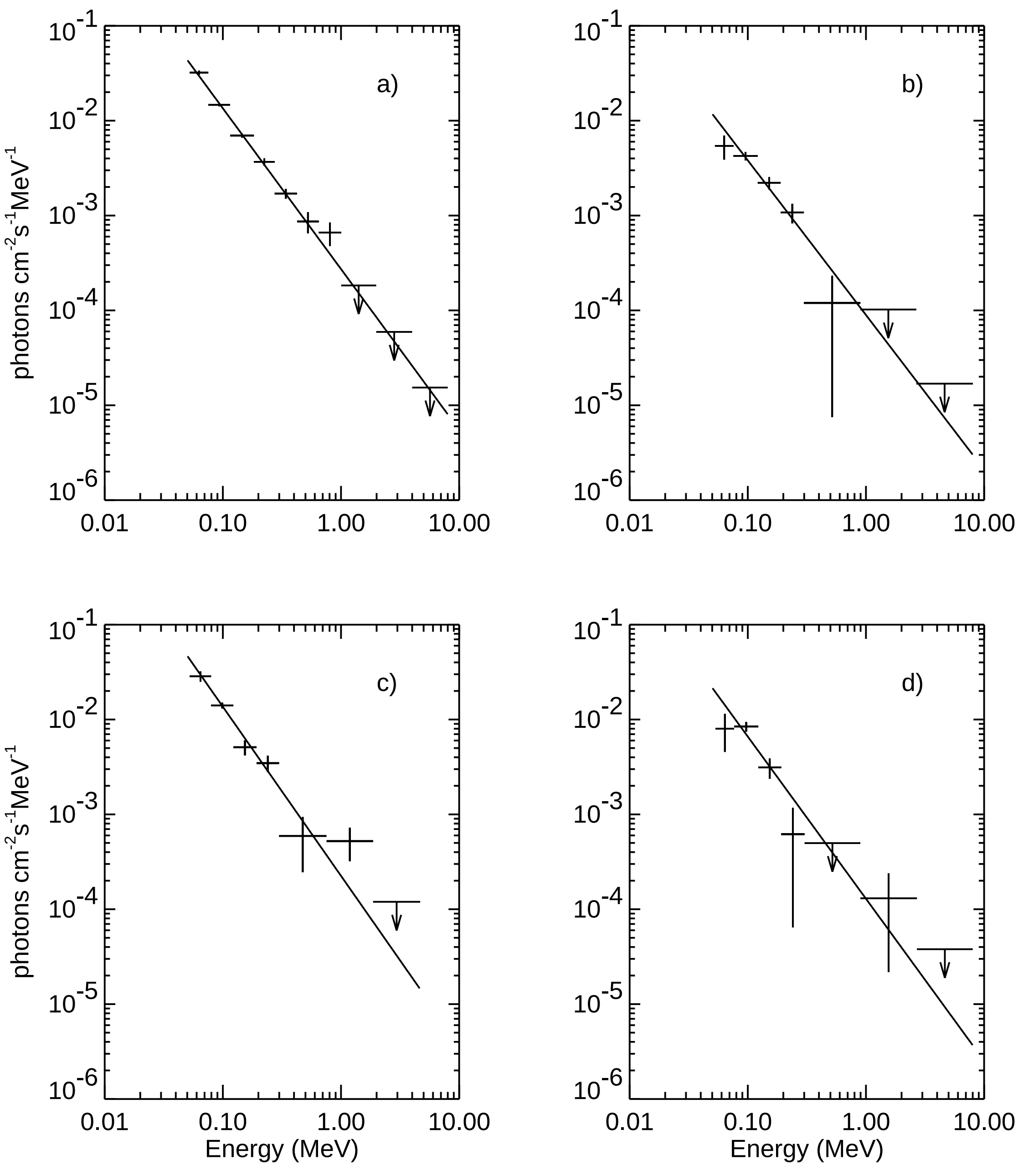

Fig. 2.— The deconvolved photon spectra measured during four observing intervals are displayed with the best fit power law model. a) 1991 June observation, b) combined observations from 1991 Aug. and Oct., c) combined observations from 1992 Aug. and Sep., and d) combined observations from 1992 Dec. and 1993 Jan.

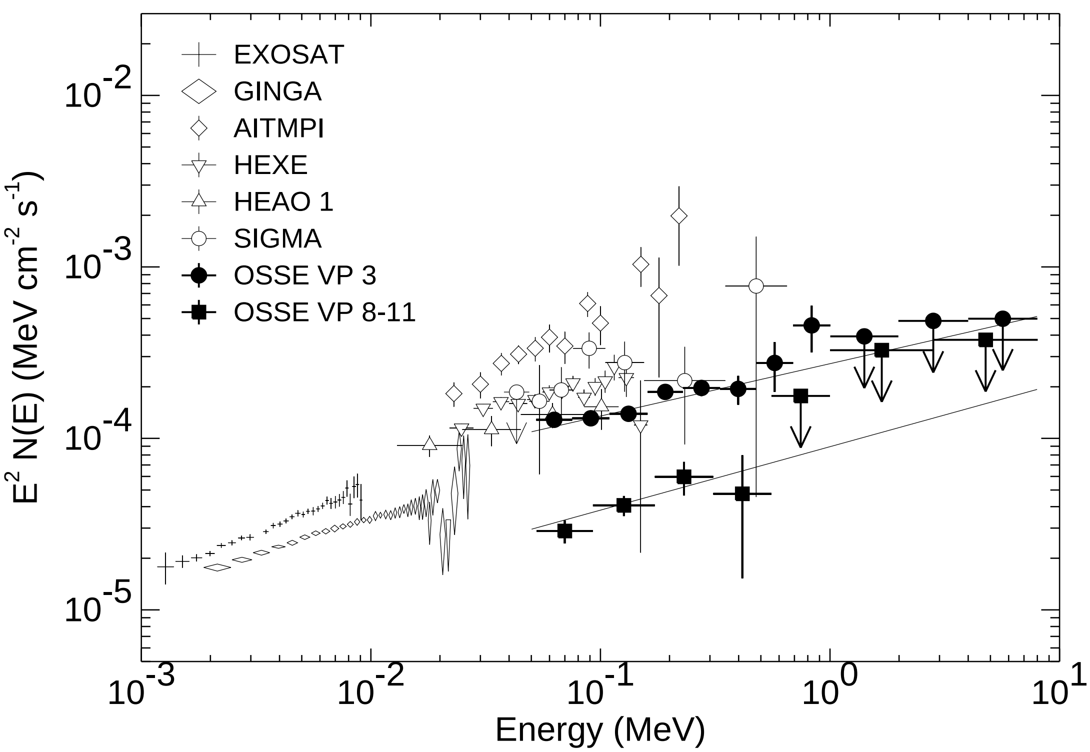

Fig. 3.— The 1991 OSSE observations of 3C 273 compared with previous X-ray and gamma ray observations. The data are displayed as $E^2\times$ differential photon flux. The OSSE VP 3 (1991 June) observation represents the highest flux observed from 3C 273 by OSSE; the VP 8 – 11 (August & October) level is the lowest state observed by OSSE. The EXOSAT and GINGA data are from Turner et al. (1990), AIT/MPI from Bezler et al. (1984), HEXE from Maisack et al. (1992), HEAO 1 from Primini et al. (1979) and SIGMA from Bassani et al. (1992).

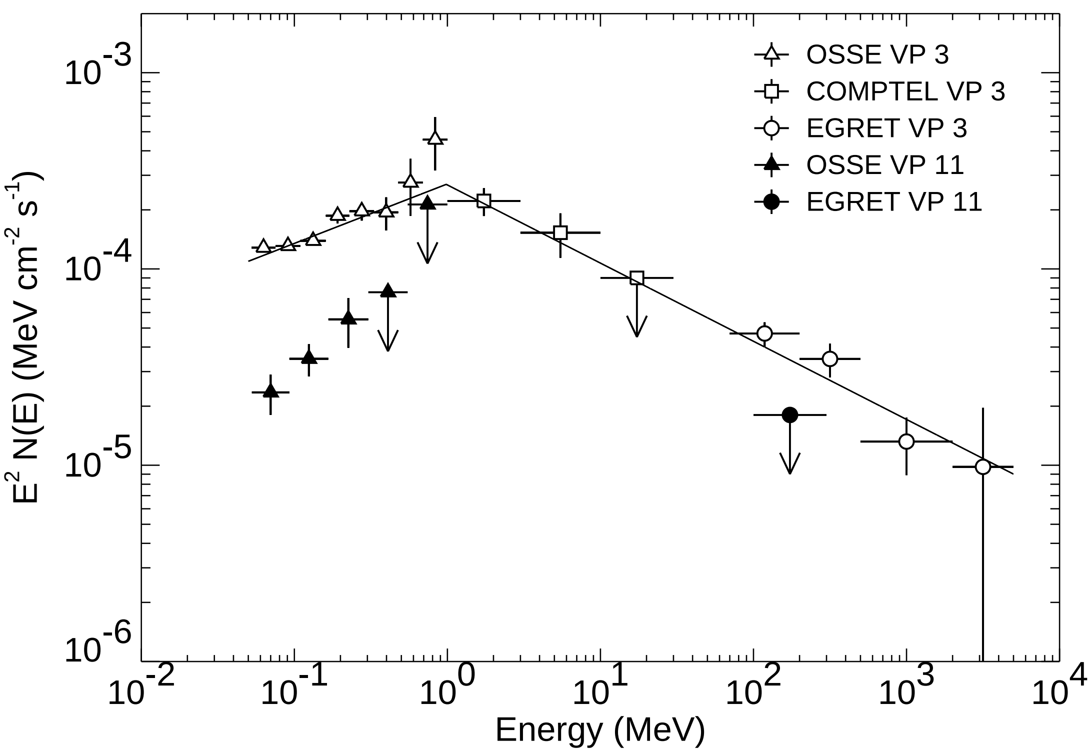

Fig. 4.— The Compton CGRO spectrum of 3C 273 displayed as E$^2\times$ differential photon flux. The open symbols are contemporaneous measurements from 1991 June (VP 3). The filled symbols indicate contemporaneous OSSE and EGRET measurements from 1991 Oct. (VP 11). The solid line indicates the best fit to the June data consisting of a broken power law. The EGRET data is from Montigny et al. (1993) and Fichtel et al. (1994); the COMPTEL data is from Lichti et al. (1994).