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DETECTION OF HIGH-ENERGY GAMMA RADIATION FROM QUASAR 3C 279 BY THE *EGRET* TELESCOPE ON THE *COMPTON GAMMA RAY OBSERVATORY*

R. C. HARTMAN,[1] D. L. BERTSCH,[1] C. E. FICHTEL,[1] S. D. HUNTER,[1] G. KANBACH,[2] D. A. KNIFFEN,[3] P. W. KWOK,[4] Y. C. LIN,[5] J. R. MATTOX,[1,6] H. A. MAYER-HASSELWANDER,[2] P. F. MICHELSON,[5] C. VON MONTIGNY,[2] H. I. NEL,[7] P. L. NOLAN,[5] K. PINKAU,[2] H. ROTHERMEL,[2] E. SCHNEID,[8] M. SOMMER,[2] P. SREEKUMAR,[7] AND D. J. THOMPSON[1]

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ABSTRACT

Intense gamma radiation has been observed from the direction of the quasar 3C 279 throughout the energy range from 30 MeV to over 5 GeV by the *Energetic Gamma Ray Experiment Telescope* (*EGRET*) during the period 1991 June 15–28. Its spectrum is well represented by a photon differential power-law exponent of 2.0 ± 0.1, with a photon intensity above 100 MeV of $(2.8 \pm 0.4) \times 10^{-6}$ cm^{-2} s^{-1}. 3C 279 was not detected by either of the earlier high-energy gamma-ray telescopes *SAS 2* or *COS B*. For $E > 100$ MeV, the 2 σ upper limits were 1.0×10^{-6} cm^{-2} s^{-1} in 1973 from the *SAS 2* observations and 0.3×10^{-6} cm^{-2} s^{-1} for the combined 1976, 1978, and 1980 *COS B* observations. Hence, there has been a large increase in high-energy gamma-ray intensity relative to the earlier times, as there has been in the radio, infrared, optical, and X-ray ranges. This source is the most distant and by far the most luminous gamma-ray source yet detected.

Subject headings: gamma rays: observations — quasars: individual: 3C 279

1. INTRODUCTION

The optically violent variable (OVV) quasar 3C 279 ($z = 0.538$) has exhibited several types of activity over the time it has been observed. It was the first quasar in which apparent superluminal motion was detected (Whitney et al. 1971), and that type of activity continues (e.g., Unwin et al. 1989). Makino et al. (1989) have observed a 20% change in X-ray intensity (2–10 keV) on a time scale of less than 1 hr. In 1988 and 1989, its luminosity in the radio, infrared, optical, and X-ray bands increased and reached a maximum level as much as an order of magnitude higher than that seen earlier (Robson et al. 1988; Kidger & Allan 1988; Makino & Ohashi 1989). Since late 1990, the radio brightness of 3C 279 has again increased, to an even higher level than in 1988, and its X-ray intensity has reached a level similar to that in 1988 (Makino, Fink, & Clavel 1991). This unusual level of activity, as well as the general character of 3C 279, suggest that it is a prime target for study in the high-energy gamma-ray range. It was, for example, one of four quasars listed by Kanbach et al. (1988) as likely candidates to be examined by the *Energetic Gamma Ray Experiment Telescope* (*EGRET*) on the *Gamma Ray Observatory* (*GRO*) in high-energy gamma rays.

In this *Letter*, the *EGRET* detection of 3C 279 in high-energy gamma rays is reported. As described below, it was found to be a very intense source, with gamma rays detected from 30 MeV to more than 5 GeV.

2. THE OBSERVATION

The *EGRET* telescope has an effective area of 1.5×10^3 cm^2 around 0.5–1 GeV, about 10 times larger than the *SAS 2* and *COS B* high-energy gamma-ray telescopes flown in the 1970s. It has the typical components used in high-energy gamma-ray telescopes: an anticoincidence system to discriminate against charged particle radiation, a spark chamber system with interspersed conversion material to convert the photons and determine the trajectories of the secondary electron-positron pair, a triggering telescope that detects the presence of the pair with the correct direction of motion, and an energy measuring device, which in the case of *EGRET* is a NaI(Tl) crystal. Descriptions and general capabilities of the instrument are given by Hughes et al. (1980) and Kanbach et al. (1988, 1989). The detailed results of the instrument calibration, both before and after launch, are given by Thompson et al. (1992). The telescope covers the energy range from about 20 MeV to over 20 GeV. Because of the very low flux level of the high-energy gamma rays, the observing period for the data presented here was about 2 weeks, which is typical for *EGRET*. The instrument is designed to be free of internal background, and the calibration tests have verified that the internal background is at least an order of magnitude below the extragalactic gamma radiation. Hence, the only significant background gamma radiation in the region of the source is from the extragalactic diffuse radiation and the Galactic diffuse component, which is low because of the high Galactic latitude of the source region.

The observation of the sky region containing 3C 279 was made during the period 1991 June 15–28, during which time the quasar was about 10° from the *EGRET* instrument axis. Standard *EGRET* data processing (Bertsch et al. 1989; Thompson et al. 1992), including automatic computer processing as well as manual event reconstruction as needed, was performed to provide optimal estimates of the direction and energy of each photon.

[1] NASA/Goddard Space Flight Center, Code 662, Greenbelt, MD 20771.
[2] Max-Planck Institut für Extraterrestrische Physik, 8046 Garching, Munich, Germany.
[3] Hampden-Sydney College, P.O. Box 862, Hampden-Sydney, VA 23943.
[4] NAS/NRC Postdoctoral Research Associate, NASA/GSFC, Code 662, Greenbelt, MD 20771.
[5] Hansen Experimental Physics Laboratory, Stanford University, Stanford, CA 94305.
[6] GRO Science Support Center, Computer Sciences Corporation, NASA/GSFC, Code 668.1, Greenbelt, MD 20771.
[7] Universities Space Research Association, NASA/GSFC, Code 662, Greenbelt, MD 20771.
[8] Grumman Aerospace Corporation, Mail Stop A01-26, Bethpage, L.I., NY 11714.

3. RESULTS

Since the celestial background around the observed source is both very weak and also uniform, a centroid position of the observed photons was determined for the four gamma-ray energy intervals 0.07–0.15 GeV, 0.15–0.50 GeV, 0.50–2.0 GeV, and >2.0 GeV. As they were found to be consistent, the weighted average was found to be R.A. (2000) = 194°.04 ± 0°.04, decl. (2000) = −5°.72 ± 0°.04, about 4′ from the known position of 3C 279. Since the 4′ difference is consistent with the uncertainty in the *EGRET* position determination, and on the basis of its current flaring state, 3C 279 is identified as the source of the gamma radiation reported here. The closest alternative object, the X-ray–identified active galactic nucleus (AGN) 1E 1253.6−0539 (Gioia et al. 1984), is about 13′ from the *EGRET* position, and the X-ray intensity of this object is an order of magnitude lower than that from 3C 279 even when the latter is quiescent.

The spectrum of the detected emission is well represented by the power law

$$\frac{dI}{dE} = (2.7 \pm 0.3) \times 10^{-7} E^{-(2.02 \pm 0.07)}\ \mathrm{cm^{-2}\ s^{-1}\ GeV^{-1}}\ . \quad (1)$$

Figure 1 shows the observed spectrum with the best power law from a least-squares fit; the 1 σ errors are statistical only. The integral photon intensity above 100 MeV is $(2.8 \pm 0.4) \times 10^{-6}$ cm^{-2} s^{-1}. Although the sensitivity analysis is still undergoing some refinement, the systematic errors associated with the instrument sensitivity values are believed to be less than 15% except below 70 MeV. The sensitivity in the 50–70 MeV region is currently less well known; this interval was not included in the determination of the constants in equation (1). It also should be noted that the flux shown for the 2–5 GeV range is based on 32 photons, while the 5–10 GeV range is based on only two gamma rays.

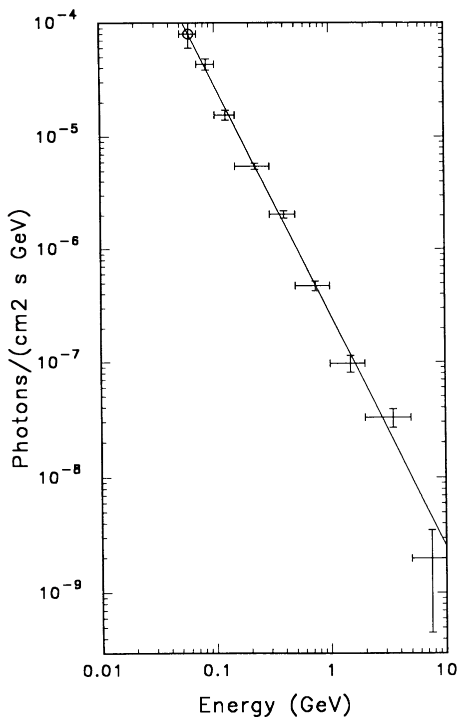

FIG. 1.—Differential high-energy gamma-ray spectrum observed for 3C 279 during the period 1991 June 15–28. See the note in the text regarding the lowest *EGRET* energy interval, shown by a circle.

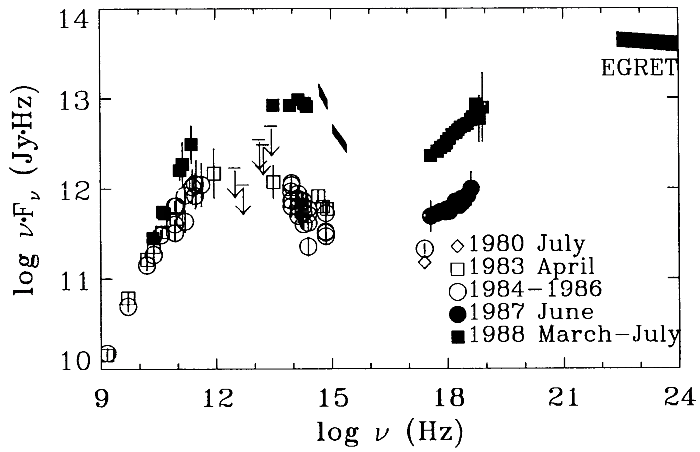

FIG. 2.—The representation of the multifrequency spectrum of 3C 279 for the quiescent (*open symbols*) and enhanced (*filled circles*) periods are adapted from Makino et al. (1989). The quiescent data are from Wilkes & Elvis (1987), Landau et al. (1986), and Brown et al. (1989). The enhanced data from the period 1988 March–July are from Urry (1988), Peterson, Wagner, & Korista (1988), Neugebauer & Matthews (1988), Teräsranta et al. (1992), and Matsuo et al. (1989). The data of this work are indicated by the word *EGRET*.

Figure 2 combines the present result with measurements in lower frequency ranges. It is seen that the energy output per logarithmic energy interval observed in the high-energy gamma-ray band is larger than in any other frequency band. (Note, however, that the *EGRET* observations are not simultaneous with those at lower frequencies.) Also, a comparison of the slopes of the spectra in the X-ray and gamma-ray ranges suggests that the spectrum must steepen between these two photon energy ranges. This characteristic has been seen before in that upper limits for various types of AGNs obtained from *SAS 2* (Bignami et al. 1979) and *COS B* (Pollock et al. 1981) indicated that the photon spectrum had to steepen substantially between 0.5 and 30 MeV (for a summary see, e.g., Fichtel & Trombka 1981). Results from the lower energy gamma-ray instruments on *GRO* will be of interest in this regard when they are available. The 3C 279 spectrum shown in Figure 1 also suggests that the photon emission may extend to higher energies. It must be remembered that the *EGRET* observation of 3C 279 may represent a relatively short-lived, nonequilibrium state.

4. SUMMARY AND DISCUSSION

This is only the second reported detection of a quasar in high-energy gamma radiation; 3C 273 was detected by *COS B* at a significance of 8 σ with an intensity roughly a factor of 4 lower than that reported here for 3C 279 (Swanenburg et al. 1978; Bignami et al. 1981; Hermsen et al. 1981). 3C 279 is thus the most distant and, by a factor of about 60, the most luminous gamma-ray source seen thus far. In the X-ray band, its minimum luminosity is fairly typical of OVV quasars; its relatively small distance makes it among the brightest. During the 1988 and 1990–1991 outbursts, it became one of the most luminous OVVs.

At the time of the observation, the high-energy gamma-ray emission may have been the dominant energy output. If the emission from 3C 279 is isotropic, its gamma ray luminosity between 100 MeV and 10 GeV is about 1.6×10^{51} photons s^{-1}, or approximately 1.1×10^{48} ergs s^{-1} for $H_0 = 75$ km s^{-1}

Mpc^{-1}. Should this be true and the central object be a black hole, the Eddington limit would imply a mass near $10^{10}\ M_\odot$. However, as discussed below, it may very well be that the emission is beamed; for 1 sr, it would be about 9×10^{46} ergs s^{-1}, for example. For comparison, our own Galaxy emits approximately 5×10^{38} ergs s^{-1} ($E > 100$ MeV).

Based on data from *SAS 2* (Fichtel et al. 1978) and *COS B* (Mayer-Hasselwander et al. 1985), 2 σ upper limits have been calculated for 3C 279. In units of $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$, they are 1.0×10^{-6} ($E > 100$ MeV) for SAS 2 in 1973 January and about 0.3×10^{-6} ($E > 100$ MeV) for *COS B*, averaged over 1976 May–June, 1978 June–July, and 1980 June–July. The *EGRET* detection indicates a marked increase in the high-energy gamma-ray output of the quasar, similar in magnitude to those seen in the optical and X-ray bands in 1988. Since there were only upper limits from the earlier gamma-ray observations, the actual magnitude of the increase cannot be determined. Webb et al. (1990) indicate that 3C 279 was quiescent in the optical band during the 1972–1980 time period of the *SAS 2* and *COS B* observations.

Numerous mechanisms have been suggested for producing gamma radiation in association with quasars. Only a sample of these is addressed here, to illustrate the range of processes which have been considered.

Synchrotron self-Compton radiation is likely to be important (e.g., Grindlay 1975; Shapiro & Salpeter 1975; Mushotzky 1976; Maraschi & Treves 1977). However, in a region of sufficiently high photon density, gamma rays can be depleted by photon-photon interactions (Jelley 1976). Simple synchrotron self-Compton models generally predict a change in spectral slope between the X-ray and gamma-ray regions, making the observation of high-energy gamma rays unlikely. High-energy gamma rays might be expected in significant quantities from second-order Compton scattering (Bergeron & Salpeter 1971; Jones 1979) in certain situations; however, unless the X-ray luminosity at the time of the *EGRET* observation was at least a factor of ~ 5 higher than in 1988, the second-order Compton process appears incapable of producing a gamma-ray luminosity as high as that observed. The gamma-ray emission might occur well out in a jet of inhomogeneous expanding plasma, where the Lorentz factor is greater and shocks propagating along the jet can further accelerate the electrons (Bregman 1990).

Another approach to extracting the energy is the model of Kazanas (1989) and Giovanoni & Kazanas (1990), in which relativistic neutrons escape from the central source, decaying to electrons and protons in a less dense region. These protons produce π° gamma rays and secondary electrons, which in turn produce additional gamma rays via inverse Compton scattering. The predicted spectrum from this model is significantly steeper than that presented here; in addition, the model appears to be incapable of generating the observed luminosity.

The massive black holes postulated to exist at the centers of active galaxies may lead to gamma-ray production through the Penrose quantum processes (see, e.g., Leiter & Kafatos 1978; Kafatos & Leiter 1979). To be compatible with the observation reported here, the Penrose pair production (PPP) process must dominate over the Penrose Compton effect. The PPP process would predict a significant steepening around a few GeV, which cannot be ruled out by the *EGRET* result.

An accretion disk model involving a 10^{12} K ion gas (Eilek 1980) may also produce energetic gamma rays. They would result both from positrons in the 35 MeV range and electron positron pairs in the 20–50 MeV range. Although energies up to 1 GeV can occur, the gamma-ray spectrum would be expected to decline rapidly with increasing energy, in contrast to the spectrum of Figure 1. The particles that are formed, however, may be of interest as the seed particles for jets.

There may be processes associated with quasar jets that involve interactions of highly relativistic electrons and protons with the interstellar medium, as suggested by Morrison, Roberts & Sadun (1984) and discussed also by Sadun (1988) in relation to the diffuse extragalactic radiation. The particle acceleration is presumed to be associated with shocks; an upper limit to the electron and proton energies may exist due to synchrotron emission and photon interactions (Biermann & Strittmatter 1987). Assuming the energetic particles themselves have a spectrum which is a power law in energy, a spectrum similar to that which is observed could result either from the bremsstrahlung or from a combination of bremsstrahlung and nuclear interactions if the former is dominant below about 100 MeV so that the π° maximum is not clearly seen, as in the case of the diffuse radiation from our Galaxy (Kniffen & Fichtel 1981).

The jet origin is an attractive one from the standpoint of variability, since the processes involved in the jet may be unstable. Nevertheless, it appears likely that the gamma-ray luminosity reported here will be a severe problem for any of the existing models.

The shape and spectral index observed here suggest the presence of an extraordinary source of relativistic particles with an energy spectrum at least as hard as that observed for charged cosmic rays near Earth. There is no way of knowing from these data whether this spectrum extends across the many additional decades to the extreme energy required by the extragalactic part of the cosmic ray spectrum. However, this evidence for a large concentration of relativistic particles in a quasar, with energies extending to at least 10 GeV, could provide some support for the concept that quasar jets may be the source of the extragalactic cosmic rays, as suggested by Colgate (1990). Gamma-ray observations of 3C 279 in its flaring state by ground-based TeV- and PeV-energy telescopes could prove to be valuable in addressing this question. A spring 1989 observation around 1 TeV by Vacanti et al. (1989) produced only upper limits; note, however, that the X-ray emission had nearly returned to its quiescent level by that time.

We wish to acknowledge the important contributions to the *EGRET* program over many years by Robert Hofstadter and E. Barrie Hughes until their deaths shortly before the *GRO* launch.

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