SIMULTANEOUS OBSERVATIONS OF THE CONTINUUM EMISSION OF THE QUASAR 3C 273 FROM RADIO TO γ-RAY ENERGIES

G. G. Lichti, C. von Montigny
Max-Planck Institut für extraterrestrische Physik, 85748 Garching, Germany.
T. Balonek
Colgate University, Hamilton, NY 13343, USA
T. J.-L. Courvoisier
Observatoire de Genève, Chemin des Maillettes 51,
CH-1290 Sauverny, Switzerland
N. Johnson
Naval Research Laboratory, Washington DC 20375, USA
M. McConnell
University of New Hampshire, Durham NH 03824, USA
W. Paciesas
Department of Physiscs, University of Alabama, Huntsville AL 35899, USA
E. I. Robson
Joint Astronomy Centre, University Park, Hilo HI 96720, USA
A. Sadun
Bradley Observatory, Agnes Scott College, Decatur GA 30030, USA
C. Schalinski, H. Steppe+
Institut für Radioastronomie im Millimeterbereich, Grenoble, France
A. G. Smith
Department of Astronomy, University of Florida, Gainesville FL 32611, USA
R. Staubert
Astronomisches Institut der Universität Tübingen, 72076 Tübingen, Germany
B. N. Swanenburg
Laboratory for Space Research Leiden, NL-2300 RA Leiden, The Netherlands
M. J. L. Turner
Department of Physics, University of Leicester, Leicester LE17RH , UK
M.-H. Ulrich
European Southern Observatory, Karl-Schwarzschildstr. 2,
85748 Garching, Germany
O. R. Williams
Astrophysics Division, Space-Science Department of ESA/ESTEC,
NL-2200 AG Noordwijk, The Netherlands

ABSTRACT

From June 15-28, 1991 the Compton Gamma-Ray Observatory (CGRO) observed the radio-loud quasar 3C 273. All four CGRO instruments detected radiation from this quasar in their relevant energy range (from 20 keV to 5 GeV). Simultaneous and quasi-simultaneous observations by instruments sensitive at other wavelengths have also been obtained. The data from all these observations, spanning the frequency range from $\sim 10^9$ Hz - $\sim 10^{26}$ Hz, were collected and analysed. Details of the observations and an overall energy-density spectrum are presented. This spectrum shows two maxima of nearly equal strength. One is in the UV, while the other one is found at low-energy γ-rays. The implications of these simultaneous observations on some theoretical models will be discussed.

INTRODUCTION

The detection of more than 20 Active Galactic Nuclei (AGNs) by EGRET has drawn the attention of the scientific community to these exotic objects, whose nature is still a mystery. In order to understand the physical processes which power these

+ Hans Steppe perished on June 30, 1993 during a hiking tour in the Alps sources, simultaneous observations across the electromagnetic spectrum are essential. Therefore an international observation campaign was initiated by R. Staubert to observe 3C 273 in several different wavelength bands in conjunction with the Compton Gamma-Ray Observatory. These observations were carried out, their data analysed and an overall energy-density spectrum was constructed. The results of this analysis are presented here.

THE OBSERVATIONS

The observations reported here took place between May 1991 and July 1991. But most of them were performed around the two-week period when CGRO observed 3C 273 (from June 15 - 28, 1991). A summary of the observations is given in Table I. More details on the observations will be given in a forthcoming publication (Lichti et al., in preparation).

Table I: Observation Summary

Date	wavelength	observer	observatory
91/06/14	18 cm	Witzel	Effelsberg
91/06/11	6 cm	Witzel	Effelsberg
91/06/13	6 cm	Pauliny-Toth	Effelsberg
91/06/16	3.3 cm	Courvoisier	Metsähovi
91/06/23	1.3 cm	Pauliny-Toth	Effelsberg
91/06/24-26	3.3 mm	Balonek	NRAO Kitt Peak
91/06/14	3.3 mm	Staubert, Steppe	Pico-Veleta
91/06/25	2 mm	Staubert, Steppe	Pico-Veleta
91/06/10	2 mm	Robson	Mauna Kea
91/06/16	1.3 mm	Staubert, Steppe	Pico-Veleta
91/06/10	1.3 mm	Robson	Mauna Kea
91/06/10	1.1 mm	Robson	Mauna Kea
91/06/10	800 μ	Robson	Mauna Kea
91/06/10	450 μ	Robson	Mauna Kea
91/06/10	350 μ	Robson	Mauna Kea
91/06/16	3.80 μ	Courvoisier	La Silla
91/06/16	2.20 μ	Courvoisier	La Silla
91/06/16	1.65 μ	Courvoisier	La Silla
91/06/16	1.25 μ	Courvoisier	La Silla
91/05/27	9000 Å	Sadun	Lowell Observatory
91/05/27	7000 Å	Sadun	Lowell Observatory
91/05/27	5500 Å	Sadun	Lowell Observatory
91/05/27	4400 Å	Sadun	Lowell Observatory
91/06/16-19	4400 Å	McNamara	Blue Mesa Observatory
91/06/02	4360 Å	Smith	Rosemary-Hill Observatory
91/06/17	1700 Å	Ulrich	IUE
91/06/17	1292 Å	Ulrich	IUE
91/06/12-13	2-37 keV	Turner, Williams	GINGA
91/06/15-28	20-320 keV	Paciesas	BATSE
91/06/15-28	60 keV - 10 MeV	Johnson	OSSE
91/06/15-28	1-30 MeV	Hermsen	COMPTEL
91/06/15-28	70-5000 MeV	v. Montigny	EGRET
91/05/14	>0.55 TeV	Lawrence, Weekes	Whipple Telescope

ANALYSIS

To allow a comparison of data measured with different instruments in different wavebands some transformations of the data are necessary. These transformations from the different units into a common flux unit are not always straightforward and require a deep knowledge of the various instrument characteristics. In particular, the filter profiles from the various optical and IR telescopes differ slightly from each other. We have, therefore, taken great care that all these characteristics have been considered when transforming the measured magnitudes into fluxes. All magnitudes were corrected for interstellar extinction using the extinction law of Seaton (1979) and the reddening value for the direction to 3C 273 (l=289.89^0, b=64.352^0) from the maps of Burstein and Heiles (1982) which give E(B-V) $\approx$ 0.02. The corrections varied from 0.03 (for the I-filter) to 0.08 (for the B-filter) magnitudes. The upper flux limit at 0.55 TeV was transformed into an upper limit of the energy density assuming an E^{-2} differential energy spectrum yielding a value of $6.512 \cdot 10^{-12} erg/(cm^2 s)$.

THE ENERGY-DENSITY SPECTRUM

An energy-density spectrum for those data which were measured exactly at the time of the CGRO observation is shown in Figure 1. Apart from the good coverage at γ-rays the data at other frequencies are sparse (but nevertheless we want to stress that it is the first time that such a spectrum has been measured). The only clear feature visible in this spectrum is a break at low γ-ray energies. A more accurate analysis assuming a broken power law yields a break energy of (2 $\pm$ 1.5) MeV.

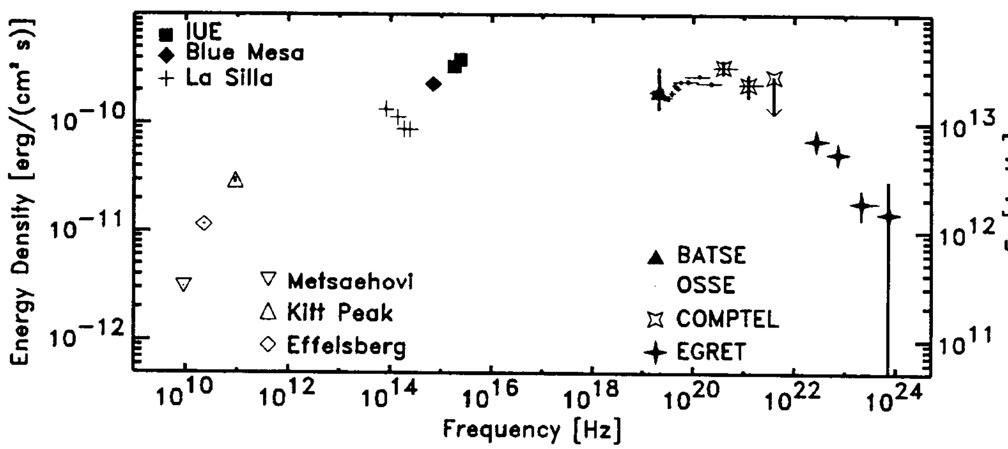

Figure 1: Energy-density spectrum of 3C 273 for simultaneous observations.

Since, apart from occasional short bursts like the one observed at radio and IR wavelengths (Robson et al., 1993) the variability timescale of 3C 273 is normally of the order of a month and more (Courvoisier and Camenzind, 1989) a quasi-simultaneous energy-density spectrum was constructed including data measured a few weeks before and after the CGRO observation (from May 27 - July 25, 1991). This spectrum is shown in Figure 2. A more complete picture emerges now. At radio frequencies a steep increase of the luminosity is observed reaching a maximum somewhere in the IR.

In the near IR the luminosity drops to a minimum around $2 \cdot 10^{14}$ Hz arriving at an isotropic luminosity of $\sim 7 \cdot 10^{45}$ erg/s (for $H_0 = 60(km/s)/Mpc$ and $q_0 = 0.5$). From optical to UV the luminosity rises again reaching a maximum in the UV. Here the absolute maximum luminosity ($3.1 \cdot 10^{46}$ erg/s) is reached, probably associated with the hot component of the blue bump (Walter and Courvoisier, 1992). The luminosity at hard X-rays increases again until it reaches a maximum around 2 MeV of $2.7 \cdot 10^{46}$ erg/s. Then the luminosity drops rapidly towards higher energies.

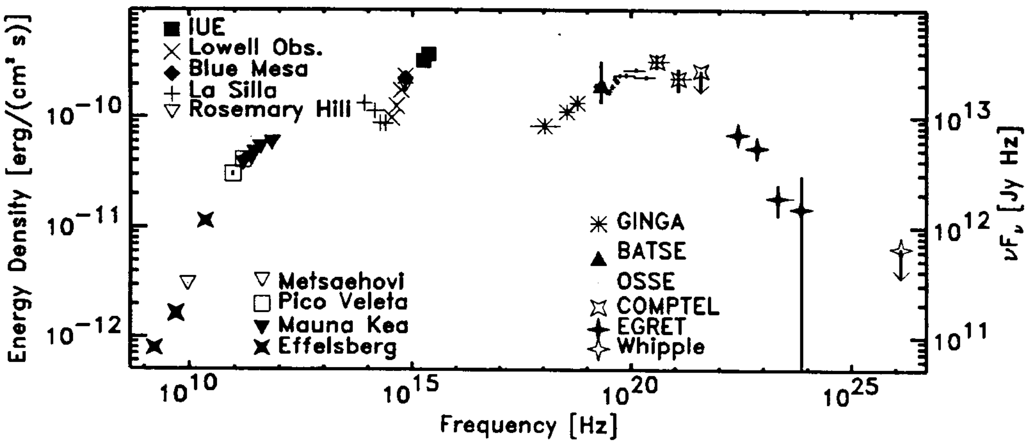

Figure 2: Energy-density spectrum of 3C 273 for quasi-simultaneous observations.

DISCUSSION

A variety of models for AGNs resembling 3C 273, in that they have a flat-spectrum radio-core, exist. But the most popular ones are those in which a rotating supermassive black hole located in the center of an active galaxy accretes matter from the surroundings forming an accretion disk. Currents flowing in the disk create according to the Dynamo principle a rotating magnetosphere. The rotating magnetic fields create jets of plasma which are ejected from the central region perpendicular to the disk. Knots filled with plasma are accelerated along the jets to relativistic energies.

The electrons moving in the magnetic fields emit synchrotron radiation which yields the spectrum observed in the radio and in the IR. The optical and UV photons are, in the case of 3C 273, emitted predominantly from a hot photosphere surrounding the accretion disk. Finally, the X- and γ-rays are produced in optically thin regions by the inverse Compton scattering involving relativistic electrons interacting with the ambient synchrotron and/or optical and UV photons from the disk. Models based on this scenario can explain the large-scale structure of the observed spectrum quite well. These models also have the advantage that the radiation is highly beamed and due to the Doppler factor (for 3C 273 $\gamma \approx 10$; Camenzind and Krockenberger, 1992; Camenzind, 1992) the luminosity is reduced by a factor of $\sim 10^4$.

Based on such a model, Dermer and Schlickeiser (1993) calculated an energy-density spectrum for the high-energy emission from 3C 273. This spectrum (solid line) is compared to the data in Figure 3. Whereas the γ-ray data are fitted reasonably well up to the highest energies it is obvious that the fit at X-rays is poor. The model cannot explain a spectral softening significantly exceeding a value of 0.5 (the observations suggest a value of ~ 0.8). Therefore, this model, in its present form, cannot explain the entire set of observational data. One possible modification to the present model would be the consideration of additional energy losses, such as adiabatic losses and/or energy-dependent escape from the acceleration region, which have not been incorporated into the existing model.

Another non-thermal model was investigated by Mannheim (1993). In this model shock-accelerated protons induce via hadronic interactions an unsaturated synchrotron cascade with electromagnetic radiation emerging as X- and γ-rays. The spectrum calculated by this model for 3C 273 is also shown in Figure 3 (dashed line). This model fits the X- and γ-rays quite nicely with two exceptions: around $5 \cdot 10^{20}$ Hz the model predictions are too low, whereas the contrary is the case around 10^{24} Hz. The flattening of the calculated spectrum around 10^{24} Hz is a well-predicted signature of this cascade model which the data seem not to support. However, no conflict with the Whipple upper limit exists as is inferred because the modelled spectrum breaks off above 10^{25} Hz due to γ-γ absorption on the IR photons of the host galaxy. Although this model is in better agreement with the data than the other one it does not completely explain the observations.

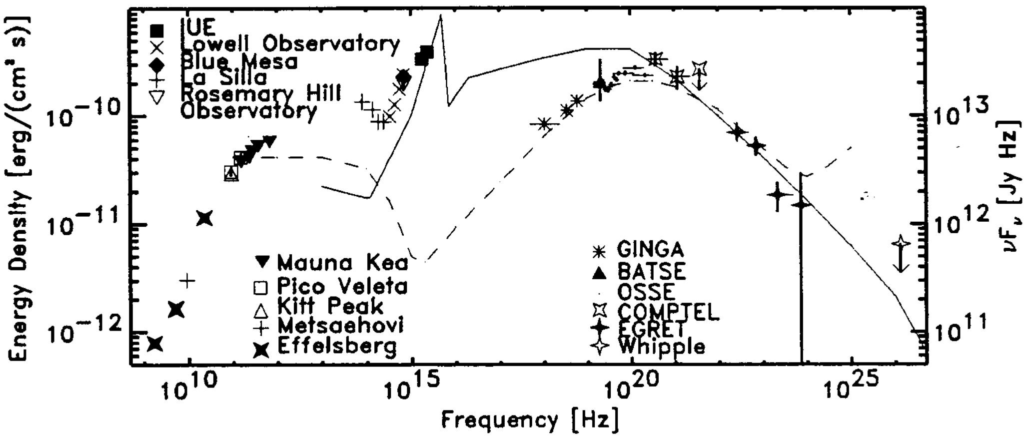

Figure 3: Comparison of the energy-density spectrum of 3C 273 with the inverse Compton model of Dermer & Schlickeiser (1993) (solid line) and with the proton-induced cascade model of Mannheim (1993) (dashed line)

CONCLUSIONS

The comparison between the two models and the data illustrates the limitation in our understanding of the emission processes of electromagnetic radiation in AGNs. It is the hope that the unique data provided by this multiwavelength study will help in gaining a better understanding of the physical processes which power these sources.

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