INTEGRAL OBSERVATIONS OF THE GAMMA-RAY BLAZAR 3C 279 DURING THE 'DEEP EXTRAGALACTIC SURVEY'

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ABSTRACT

The prominent Gamma-Ray blazar 3C 279, an optically violently variable (OVV) quasar, was observed by INTEGRAL in AO-3 several times during the so-called "Deep Extragalactic Survey", which foresaw 1 Ms of total exposure time on the Virgo sky region. The blazar was detected with 6.9σ in the 20 – 60 keV energy band at a flux level of (1.16 ± 0.24) × 10^{-11} erg cm^{-2} s^{-1}. A power-law fit between 20 and 100 keV resulted in a photon index of 2.0 ± 0.4. By combining our flux results with other INTEGRAL observations of 3C 279, we find a constant flux level at hard X-ray energies. This is in contrast to observed significant variability in the optical band, showing that there is no simultaneous correlation between the optical and the hard X-rays.

1. INTRODUCTION

The EGRET telescope on-board the Compton Gamma-Ray Observatory (CGRO) detected about 90 blazars during its mission [1]. One of the best studied of these sources is 3C 279, an OVV quasar located at a redshift of 0.538. This quasar, as all OVVs, shows variability at all wavelength bands, and also highly variable optical polarization [2]. Several multi-wavelength campaigns on 3C 279 were carried out during the last 15 years, and hence there are plenty of archival high-energy data available for this object.

According to the "Unified Scheme" for AGN, blazars are thought to be those objects viewed at a small angle to their jet axis [3]. Their observed spectral continua are predominately of non-thermal emission arising from a relativistic jet [4]. Due to beaming effects, the non-thermal emission component dominates or even outshines completely, like in the case of 3C 279, the thermal emission of a blazar. In a νF_ν representation, the non-thermal jet component shows for blazars a typical two-hump structure. 3C 279 shows such a typical blazar spectral energy distribution (SED), which is rising in the radio through millimetre band, falling in the IR through UV band, and again rising in the X-ray band and falling at GeV energies, showing the typical two-hump shape broadband (e.g., Fig. 1 from [5]).

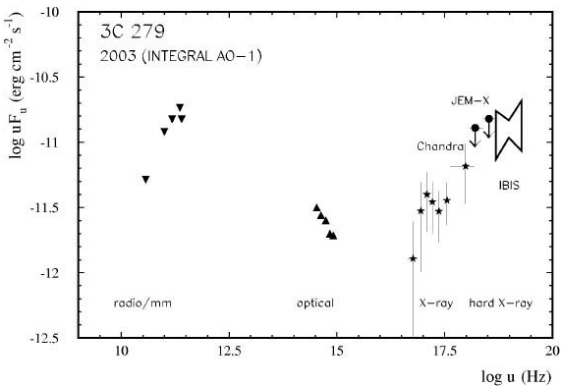

Fig. 1. The 3C 279 low-state multiwavelenght spectrum as measured during the campaign in June 2003 [5]. The broadband SED shows the typical two-hump shape.

The first spectral component is generally interpreted as being synchrotron radiation from high-energy electrons moving in a magnetic relativistic jet, which at the low end (radio to mm) is self-absorbed. The high-energy emission is believed to be IC emission, where the relativistic electrons upscatter lower-energy photons. It is still unclear, which is the dominant population of the upscattered target photons. To discriminate or at least to provide constraints on the emission models, multiwavelength variability has to considered, because the different blazar emission models make predictions on variability correlations (or anti correlations) of different spectral components.

In this paper we present the results of an analysis of the yet available 3C 279 INTEGRAL (IBIS/ISGRI, OMC) data of the so-called "Deep Extragalactic Survey", which is performed during INTEGRAL AO3. We then combine these results with similar results of other INTEGRAL observations.

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2. OBSERVATIONS

The "Deep Extragalactic Survey" consists of a rectangular dithering pattern of 5x12 (dither step 2.17°) centred on RA/DEC (J2000) = 12h34.5m/03°32'. This pattern is repeated several times, leading to a total exposure time on the Virgo sky region of 1 Ms. These observations are accomplished partly at the writing of this article, i.e. in the first visibility period of the Virgo region in May, June, and July 2005 (INTEGRAL revolutions 320, 321, 334) and in May and June 2006 (revolutions 443 to 445) leading to a total Virgo exposure time of more than 650 ks. The remaining 350 ks have still to be carried out.

Also other INTEGRAL observations were taken in account in order to investigate possible long term variations (see section 4.2). Table 1 summarizes some observational details of the analyzed observations.

Table 1. The data used in this paper are listed here below.

Observations	Exposure (s)	Science windows
June 2003 (PI obs.)	290405	88
Survey 2005 (May–July)	327145	239
January 2006 (ToO)	505043	149
Survey 2006 (May/June)	334136	162

3. DATA ANALYSIS

3.1 High-energy observations

The analysis of IBIS data have been performed using the INTEGRAL Offline Scientific Analysis (OSA) version 5.1. The most recent response matrices available for standard software were used for spectral analysis. Data screening was performed according to the median count rate with respect to each science window and their counts distributions in the energy band 20 – 60 keV. By omitting science windows having an excessively high count rate, we end up with a total of 401 science windows for the "Deep Extragalactic Survey" in 2005 and 2006. This corresponds to 659217 seconds of exposure time, for scientific analysis. They have been analysed in a combined manner, as well as by separating the 2005 and 2006 data.

3.2 Optical observations

Also the corresponding OMC (Optical Monitoring Camera) data were analyzed using OSA 5.1. OMC provides the optical flux in the Johnson V band. The flux measurement was obtained by considering a box of 3 x 3 detector pixels, which corresponds to a region on the sky of about 1 x 1 arcmin. Since OMC reports brightness measurement roughly every 10 minutes, an optical V band light curve is obtained, from which we calculated mean magnitude values by weighting on the error bars of the single points.

4. RESULTS

4.1 Deep Extragalactic Survey

For the total (2005 and 2006) of the Deep Extragalactic Survey, 3C 279 was detected by ISGRI at energies between 20 and 60 keV with a significance of 6.9σ. Fig. 2 shows an image of the sky region around 3C 279 for this period.

Fig. 2. 3C 279 is 'seen' by ISGRI with a detection significance of 6.9σ. The Seyfert galaxy NGC 4593 is with 14.6σ more significantly detected.

The hard X-ray spectrum for the sum of the data (corresponding to Fig. 2) was obtained in the energy band from 20 – 100 keV by using 6 energy bins (Fig. 3). By fitting a power-law shape (Fig. 3), we derive a photon index of 2.0 ± 0.4 (1σ), which is consistent with the value previously derived by [5]. We derive a flux (20 – 60 keV) of (1.16 ± 0.24) × 10^{-11} erg cm^{-2} s^{-1}.

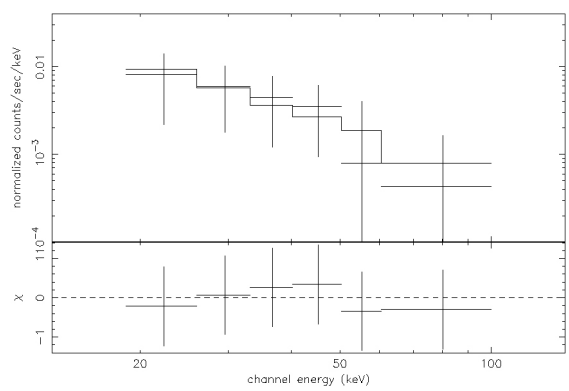

Fig. 3. The ISGRI spectrum in the energy band 20 – 100 keV with the best fit power-law is shown.

By analysing the 2005 and 2006 survey data separately, we detect 3C 279 at significance levels of 4.6σ and 5.3σ and flux levels of (1.32 ± 0.38)×10^{-11} erg

cm^{-2} s^{-1} and $(1.53 \pm 0.49)\times10^{-11}$ erg cm^{-2} s^{-1} in 2005 and 2006, respectively.
The analysis of the OMC data led to V-band light curves during 2005 and 2006. Calculating the weighted means resulted in 14.33 ± 0.01 mag for 2005, and in 14.48 ± 0.02 mag for 2006.

4.2 Combined results

In order to test for possible long-term trends, we combined our "Deep Extragalactic Survey" results with other available measurements during the INTEGRAL mission. INTEGRAL observed 3C 279 in a regular PI observation in June 2003 for 300 ks (see [5]) and in a ToO observation (PI: W. Collmar) triggered on an optical high state, in January 2006 for 511 ks, which was supplemented by a multifrequency campaign (see [6]).

To have a consistent set of results, we analysed or re-analysed the INTEGRAL ISGRI and OMC data of the June 2003 and the January 2006 observations, by using the same analysis tools (OSA 5.1) and methods as for the "Deep Extragalactic Survey" observations (see section 3). Table 1 summarizes some observational details of the analyzed observations, and Fig. 4, as an example of our analysis, shows the OMC V-band light curve for the January 2006 ToO observation. The calculated mean V-band brightness of 15.43 ± 0.01 mag, agrees well with the value of ~15.4 mag (the source varied between ~15.2 and 15.7 mag during the INTEGRAL observations), which was measured by supplementing optical observations in the multi-wavelength campaign (see [6], also for the ISGRI results of this observation).

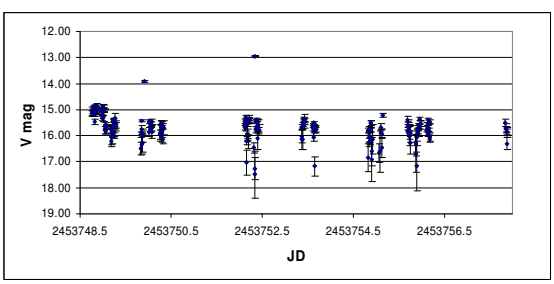

Fig. 4. The optical light curve, obtained with OMC of the ToO observation in January 2006, which was supplemented by a multifrequency campaign, is shown.

During the June 2003 INTEGRAL observation of 3C 279, also supplemented by a multifrequency campaign, the blazar was found in the deepest optical low-state of the last ten years [5]. Its V-band brightness was measured by optical telescopes to be about 17.2 mag. Because this is close to the limiting magnitude of the OMC, we use this accurately measured value instead of the result of our OMC analyses, which yielded a somewhat brighter source. The results of our analyses, i.e. the light curves of the two wavelength bands, are shown in Fig. 5. While the hard X-ray (20-60 keV) fluxes are rather constant, the optical V-band shows significant variability. This becomes even more obvious by correlating the two bands (Fig. 6). While the V-band magnitude covers a range from 14.3 to about 17.2 mag, i.e. a flux variation of about a factor of 15, the hard X-rays remain constant. This result clearly shows that there is no simultaneous variability between the two bands. The two bands seem to be uncorrelated.

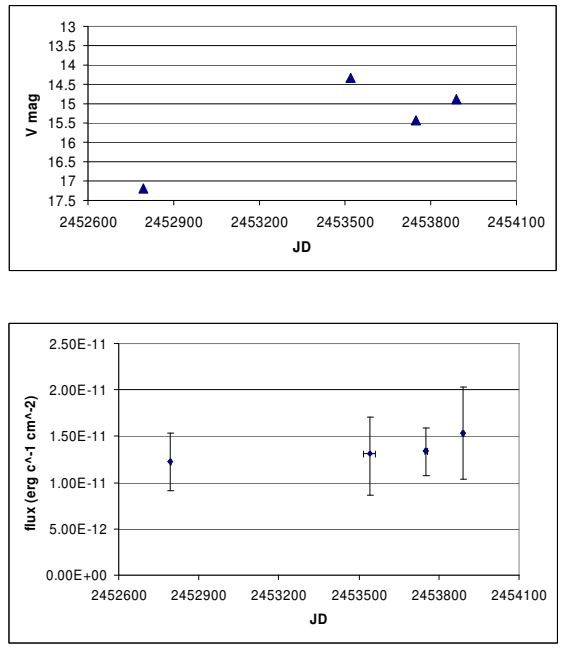

Fig. 5. Light curves in the optical V-band (top) and the ISGRI 20 – 60 keV hard X-ray band (bottom) during the four observational periods.

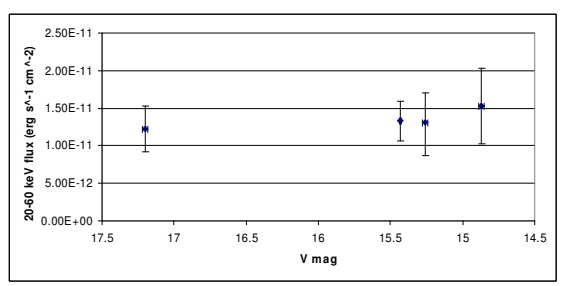

Fig. 6. The hard X-ray flux is plotted against the V-band magnitude obtained from simultaneous observations with ISGRI and OMC, or by optical telescopes for June 2003. The two bands do not show a correlation.

5. DISCUSSION

As mentioned earlier, 3C 279 shows the typical two-hump broadband SED, interpreted as non-thermal synchrotron and IC emission emanating from a relativistic jet. Most detailed blazar emission models have been developed within this scenario. While the synchrotron emission is generally understood, the detailed nature of the IC emission remains unclear. For example, it is not agreed on whether hadronic or leptonic processes dominate. If leptonic processes dominate, it is still unclear whether the leptons upscatter the synchrotron jet photons themselves, which is called the synchrotron self-Compton (SSC) mechanism ([7],[8]), or whether photons external to the jet (e.g. from an accretion disk are upscattered to higher energies ([9],[10]). The latter models are called EC (external Comptonisation) models. Since all these processes are physically possible, it might be that a combination of processes contribute to the IC emission of blazars. Such a multi-component modelling was applied to describe the multifrequency emission of 3C 279 [11]. According to this modelling the low-energy IC emission (X- and hard X-rays) is dominated by the SSC component, while the γ-rays (≥1MeV) are predominantly due to Comptonisation of photons external to the jet.

We have studied the hard X-ray emission of 3C 279 during the INTEGRAL mission. We find that over 4 observational periods, the hard X-ray flux (20 – 60 keV) is nearly constant. By considering the error bars on the flux values, 3C 279 is varying within a factor of two at most (Fig. 5). In contrast to the hard X-ray band, we find – by analysing the INTEGRAL OMC data or by taking values from the literature – significant variability in the optical V-band for the same observational periods. Variability changes between 14.3 and 17.2 mag correspond to flux changes of a factor of 14.5. Fig. 6 shows, that in spite of these large optical flux changes, the hard X-ray flux remains constant, showing that the two spectral bands are not correlated. This result means that the optical flux cannot be used as tracer to estimate the level of the hard X-rays. By assuming a leptonic emission scenario, our result – the non-correlation between optical and hard X-rays – is consistent with and therefore supports the suggestion that in 3C 279 the X- and hard X-rays are SSC emission. In simple SSC models, the IC spectrum follows to first order the shape of the curved synchrotron spectrum, just shifted to higher energies. A significant change in the optical band, being at the high-energy synchrotron part, should then have its "IC counterpart" at the higher IC energies, i.e. above the hard X-rays, e.g. at MeV or GeV energies.

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