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Optical to Far-IR Observations of 3C 446

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Abstract: The OVV blazar 3C 446 was monitored over seven months in 1997 with ground based telescopes and instruments on ESA's Infrared Space Observatory (ISO). The aim was to try to detect variations in the IR and see if these were correlated with optical variations. The object varied in the optical and near-IR during this period, but did not vary in the far-IR. Despite being a factor of ten weaker than in 1983, the optical-IR SED exhibited the same slope. The new far-IR observations from ISO allow us to determine the location of the turnover in the spectrum, caused by synchrotron self-absorption. It occurs just longwards of 100 μm.

Keywords: BL Lacertae objects: individual (3C 446) — infrared: galaxies

1 Introduction

3C 446 is an OVV blazar at $z = 1.4$ with a $L_{\rm FIR} > 10^{13}\ {\rm L}_\odot$. It exhibits rapid variability in the optical, X-ray (e.g. see Sambruna 1997), and radio (e.g. see Terasranta et al. 1998). As an OVV it can exhibit large amplitude optical flux variations on a variety of timescales. Between 1970 and 1986 it varied in B by ≈4 magnitudes (Webb et al. 1988), and between 1986 and 1992 the B variations were of the order of 2 magnitudes (Netzer et al. 1996). In 1997 (when the observations reported here were made) its optical emission was a factor of ten weaker than in 1983, and it exhibited weak optical variations over the time period of a week in June 1997 (Ghosh et al. 2000).

The motivation for this project was to observe blazars to see if they varied in the mid and far-IR. 3C 446 was chosen as a suitable target because we felt its rapid and large variability in the optical gave us a high chance of success in detecting IR flux variations. Subsidiary questions we wanted answering included: Were any IR flux variations correlated with optical variations? Does any of the IR emission originate in a thermal source? To answer these questions we intended to observe 3C 446 from the optical to the far-IR with differing delays between epochs, ranging from hours to months, to find the characteristic variability timescale in the mid and far-IR.

2 Observations

A monitoring program was organised with the Infrared Space Observatory (ISO) of the European Space Agency (ESA) (Kessler et al. 1996; see also www.iso.vilspa.esa.es), the 2.34 m telescope of the Vainu Bappu Observatory, Kavalur, India, and the 1.54 m telescope of the Observatorio Bosque Alegre, Universidad Nacional de Cordoba, Argentina. Table 1 gives the observing log.

On ISO we used the camera (ISOCAM, Cesarsky et al. 1996) and photometer (ISOPHOT, Lemke et al. 1996) to observe through five filters centred on 6.7, 14.3, 25, 60, and 170 μm. Near-simultaneous optical observations were made in the B, V, R, and I bands from the ground based observatories using CCD cameras.

The 6.7 and 14.3 μm observations were made with the ISOCAM camera, a 32×32 imaging camera. Each set of two observations lasted 550 seconds.

Each 25 μm observation lasted 1400 seconds and was made with the ISOPHOT photometer. This had a 52″ diameter aperture and observed the target in a raster chop pattern of on and off-target pointings.

The 60 and 170 μm observations were made with the ISOPHOT cameras (3×3 and 2×2 pixels respectively). Observations were made in a 3×3 raster pattern with the instrument moving approximately the size of a pixel

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Table 1. Observing log

Date	Start time/UT	Where	Wavelengths μm	TDT numbers for ISO observations only
4-May-1997	02:57:09	ISO	6.7 14.3 25 60 170	53500204 53500205 53500240 53500206
4-May-1997	03:51:25	ISO	6.7 14.3 25 60 170	53500307 53500308 53500341 53500309
4-May-1997	04:45:41	ISO	6.7 14.3 25 60 170	53500410 53500411 53500442 53500412
4-May-1997	08:54:57	ISO	6.7 14.3 25 60 170	53501513 53501514 53501543 53501515
4-May-1997	17:00:04	ISO	6.7 14.3 25 60 170	53501513 53502817 53502844 53502818
5-May-1997	08:30:53	ISO	6.7 14.3 25 60 170	53600319 53600320 53600345 53600321
5-May-1997		Argentina	V, R, I	
6-May-1997	16:21:30	ISO	6.7 14.3 25 60 170	53702822 53702823 53702846 53702824
6-May-1997		Argentina	R, I	
9-May-1997	03:15:31	ISO	6.7 14.3 25 60 170	54000325 54000347 54000327 54000326
14-May-1997	04:57:29	ISO	6.7 14.3 25 60 170	54500428 54500430 54500429 54500448
24-May-1997	10:19:42	ISO	6.7 14.3 25 60 170	55501031 55501032 55501049 55501033
4-Jun-1997		Argentina	V, R, I	
7-Jun-1997		India	V	
8-Jun-1997		India	V	
13-Jun-1997	10:11:37	ISO	6.7 14.3 25 60 170	57501134 57501135 57501150 57501136
15-Jun-1997		India	V	
13-Jul-1997		Argentina	V, R, I	
12-Aug-1997		Argentina	B, V, R, I	
2-Nov-1997	15:40:32	ISO	6.7 14.3 25 60 170	71800137 71800138 71800151 71800139
16-Nov-1997	17:12:19	ISO	25 60 100 135 170 200	73200593 73200592 73200590 73200691
20-Nov-1997		Argentina	B, V, R, I	

(46″ and 92″) between each pointing. These observations lasted 600 and 450 seconds each.

Other observations from the ISO archive, not part of our monitoring program, were also used.

3 Data Reduction

For the optical data, standard data processing techniques were applied using the standard calibrations, biases, and flat fields available at the two telescopes. The photometric analysis was carried out using Midas and the SEXTRACTOR program on sky-subtracted images. The flux of 3C 446 was measured relative to the flux of a nearby bright star present in the images, and tied to an absolute calibration with photometric standards observed at Bosque Alegre during one of the nights (20 November 1997). The accuracy of the absolute fluxes is to better than 0.15 magnitudes.

For the ISOCAM data standard pipeline products were processed with CIA (ISOCAM Interactive Analysis, Ott et al. 1997), and synthetic aperture photometry (with a 6″ aperture) was used in extracting the fluxes from the images.

For the 25 μm ISOPHOT data standard pipeline products were processed and the fluxes extracted using PIA (PHOT Interactive Analysis, Gabriel et al. 1997).

For the 60 and 170 μm ISOPHOT data standard pipeline products were processed with PIA. Individual detector drifts were removed and detector-to-detector variations flat fielded out. All pixels whose centres lay within 10″ (40″ for the 170 μm data) of the target position were considered on-source and the average of off-source pixels (defined to be more than 70″ or 100″ away) was subtracted.

4 Results and Conclusions

3C 446 was in a low state during 1997, with flux a factor of 10 lower than when observed by IRAS in 1983. Nevertheless, it did vary in the optical and near-IR during the observing period, as can be seen from Figures 1 and 2. The optical minimum was around early June 1997 (June 1 is JD-2450601), with a halving time of approximately 10 days in the rest frame. The 7, 14, and 25 μm observations also showed a minimum around this period, with a similar halving time. The far-IR (60 and 170 μm) observations did not, however, show any variations.

There was no change in the optical–IR spectral index of approximately −1.2 between 1983 and 1997, as can be seen from Figure 3. This is despite the drop in flux by a factor of 10. Neither does there seem to be a difference in the spectral index between the high and low states of 1997.

As the wavelength coverage of the ISO instruments extends to over 200 μm, compared to 100 μm for IRAS, the new data allows us to locate the turnover in the power law, caused by self-absorption. This lies between 100 μm and 170 μm. While this may be considered a very high frequency for self-absorption, for example if we use formula 3.12 from Verschuur & Kellermann (1988) it implies the magnetic field is of the order of 10^{15} G, the models have many free parameters. The alternative explanation that the emission is due to cold gas at 20–30 K has the problem that the host galaxy would then become an ultraluminous FIR galaxy, with large amounts of dust which

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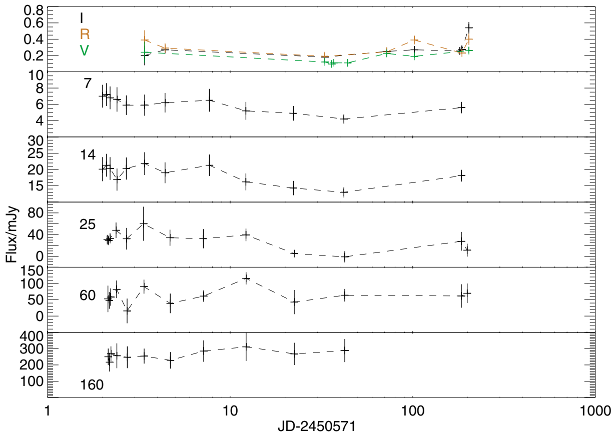

Figure 1 1997 variability of 3C 446 in log time.

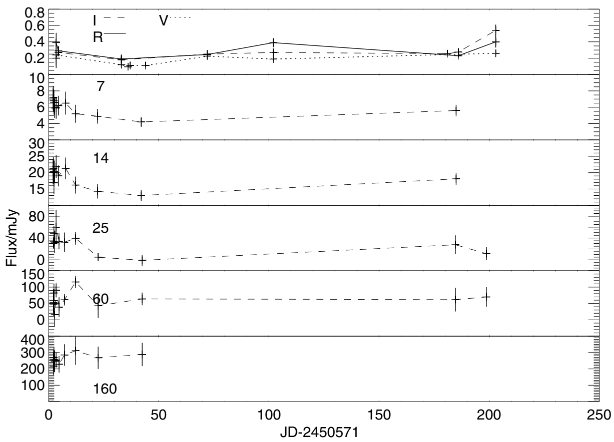

Figure 2 1997 variability of 3C 446 in linear time.

would cause extreme reddening of the optical/UV nucleus. No evidence for such reddening is seen, and therefore there is no evidence that any of the IR emission is thermal.

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The ISOPHOT data presented in this paper were reduced using PIA, which is a joint development by the ESA Astrophysics Division and the ISOPHOT Consortium with the collaboration of the Infrared Processing and Analysis Center (IPAC). Contributing ISOPHOT Consortium institutes are DIAS, RAL, AIP, MPIK, and MPIA.

The ISOCAM data presented in this paper were analysed using 'CIA', a joint development by the ESA Astrophysics Division and the ISOCAM Consortium. The ISOCAM Consortium is led by the ISOCAM PI, C. Cesarsky.

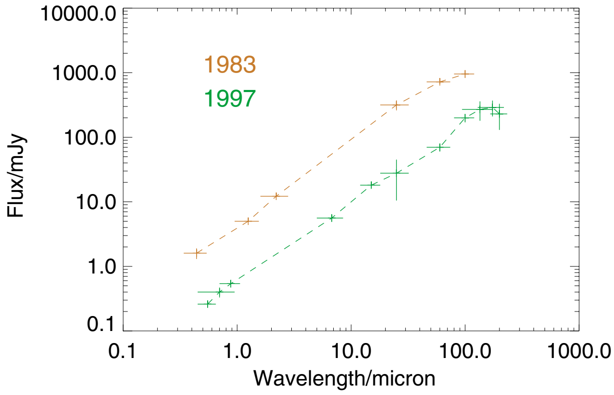

Figure 3 The 1983 and November 1997 SEDs of 3C 446. The horizontal bars indicate the bandpass of the filters, the vertical bars the error estimate. The November 1997 ISO data is from 2 November 1997, the optical data from 20 November 1997.

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