FIR POLARIZATION OF THE QUASAR 3C 279*

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ABSTRACT

These proceedings summarize our results obtained from ISOPHOT 170$\,\mu$m polarization measurements which we published in Klaas et al. (1999a), but they also provide a wider overview of the physical context. The OVV quasar 3C 279 is a strong synchrotron source with a one-sided superluminal jet. After a γ-ray burst in January 1996 we could successfully measure for the first time polarization of this source in the FIR wavelength regime at two epochs, in July 1996 and in June 1997. We found a strong polarization degree of 23 % in July 1996, well aligned with the radio jet. Nearly one year later the measured FIR polarization degree had decreased to 6.5 % with a less well alignment. We discuss the origin of this polarization and put these findings in the context of the current emission models for 3C 279.

Key words: Polarization; Radiation mechanisms: non-thermal; Galaxies: quasars: individual: 3C 279; Infrared: galaxies.

1. GENERAL PROPERTIES

The quasar 3C 279, at a redshift z = 0.538 is classified as an OVV quasar due to its strong variability in flux. This variability has the following characteristics:

- The time scale varies from a few weeks to approximately 6 months.
- The amplitude amounts to a factor of 20 in the GeV range, and a factor of 5 – 10 in the IR-optical-UV range.
- The SED hardens when the source brightens.

Furthermore, 3C 279 is a flat spectrum radio quasar and a superluminal radio source with a one-sided jet.

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2. 3C 279 EMISSION MODEL

3C 279 is one of the best observed quasars with simultaneous multi-wavelength monitoring measurements from the radio to γ-rays (e.g. Hartman et al. 1996. In a power per logarithmic bandwidth diagram the Spectral Energy Distribution (SED) shows two broad maxima, one in the unexplored FIR wavelength range, and the second one at GeV energies (Figure 1). This shows the importance of our new measurements.

The shape of the SED is explained by the following model:

- The relativistic jet pointing close to the line-of-sight dominates the emission.
- The radiation in the IR-optical-UV is optically thin synchrotron emission.
- Low frequency synchrotron self-absorption generates the flat radio spectrum.
- The radiation at X-rays and γ-rays is produced by inverse Compton (IC) up-scattering of ambient "seed" photons.

There are two possible sources for these "seed" photons:

1) They are the synchrotron photons themselves. In this case one speaks of the synchrotron self-Compton (SSC) model.
2) They are thermal photons from e.g. the accretion disk. In that case one speaks of the external Compton (EC) model.

For a discussion of both models see Sikora et al. 1997. The SSC model is favoured for the interpretation of the 3C 279 SED (see e.g. Marscher & Travis 1996).

3. SSC MODEL JET PARAMETERS

Here we outline in some detail the basic physics of the jet and its magnetic field being responsible for

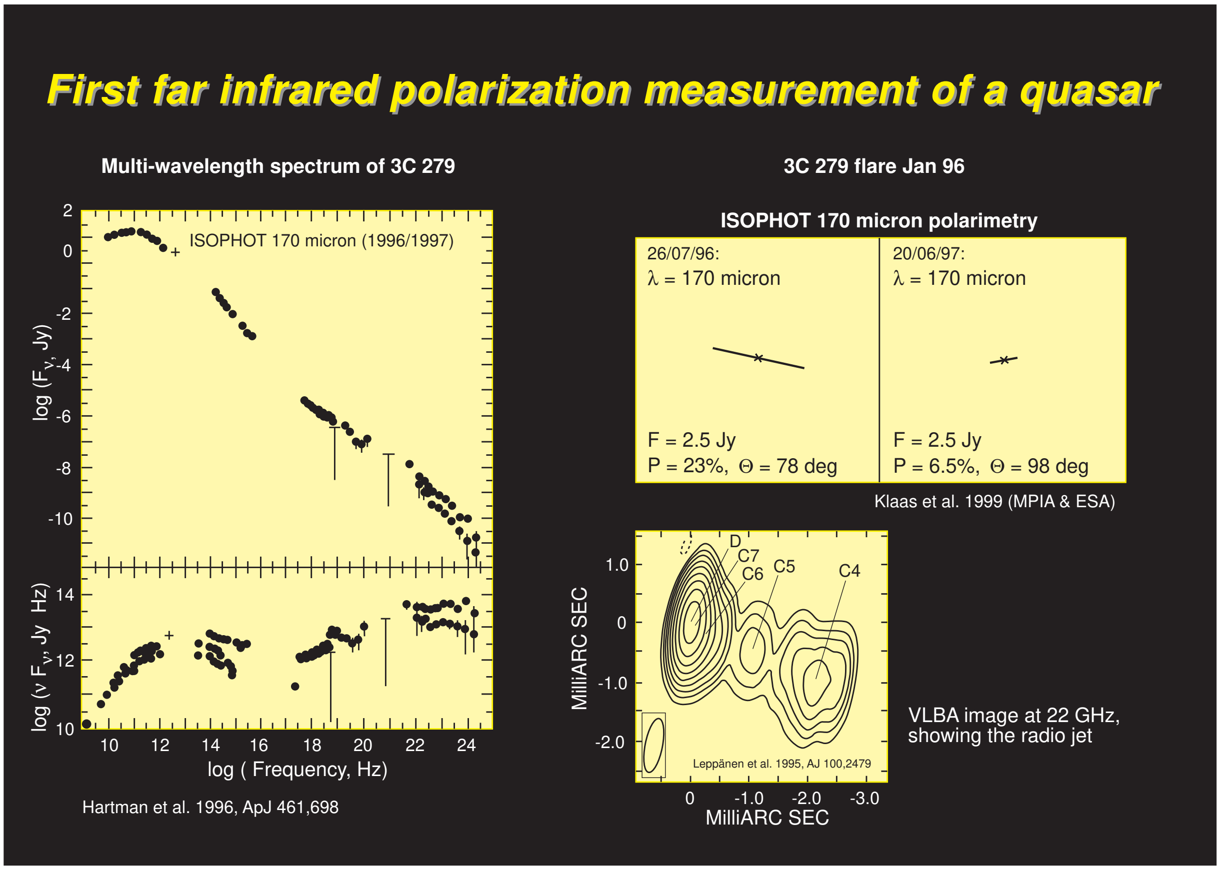

Figure 1. First FIR polarization measurements of the quasar 3C 279. The left diagram shows the multi-wavelength spectrum of 3C 279 obtained by Hartman et al. 1996 with the photometric data point from ISOPHOT obtained at a later epoch included. The upper right panel shows our polarization results from the two epochs in 1996 and 1997. The lower right panel shows the structure of the milli-arcsec radio jet as published by Leppänen et al. 1995. This is shown for the relative orientation of the polarization.

the accelaration of the electrons which produces the polarized synchrotron emission. We follow the presentation given by Ghisellini et al. (1996):

The maximum of the Inverse Compton emission $\nu_{\rm C}$ can be determined from the maximum of the synchtrotron emission $\nu_{\rm S}$ and the typical electron energy $\gamma_{\rm b}$:

$$\nu_{\rm C} \simeq (4/3)\, \gamma_{\rm b}^2\, \nu_{\rm S} \tag{1}$$

or alternatively the energy of the elctrons contributing most to the power output can be determined from the SED via:

$$\gamma_{\rm b} \simeq \left(\frac{3\,\nu_{\rm C}}{4\,\nu_{\rm S}}\right)^{1/2} \tag{2}$$

Both synchrotron & self-Compton are boosted by the same Doppler factor δ, hence:

$$B\,\delta \simeq (1\,+\,z)\frac{\nu_{\rm S}^2}{3.7\,10^6\,\nu_{\rm C}} \tag{3}$$

The knowledge of the peak frequencies for synchrotron and Inverse Compton emission alone does not allow to determine the magnetic field B and the Doppler factor δ separately. Further parameters that must be known are the luminosities at the synchrotron ($L_{\rm S}$) and Inverse Compton ($L_{\rm C}$) peaks as well as the period of the variability ($t_{\rm var}$). This yields a second relation between magnetic field and Doppler factor:

$$B\,\delta^3 \simeq (1\,+\,z)\,\left(\frac{2L_{\rm S}^2}{L_{\rm C}\,c^3\,t_{\rm var}^2}\right)^{1/2} \tag{4}$$

With equation (3) this results in:

$$\delta = 1.67\,10^4\,\left(\frac{\nu_{\rm C}}{t_{\rm d}\nu_{\rm S}^2}\right)^{1/2}\,\left(\frac{L_{\rm S,45}^2}{L_{\rm C,45}}\right)^{1/4} \tag{5}$$

and

$$B = 2.14\,10^{-11}\,(1\,+\,z)\,\frac{\nu_{\rm S}^3 t_{\rm d}^{1/2}}{\nu_{\rm C}^{3/2}}\,\left(\frac{L_{\rm C,45}}{L_{\rm S,45}^2}\right)^{1/4} \tag{6}$$

For a variability time scale $t_{\rm d} \simeq$ a few days and frequency and luminosity parameters taken from measured multi-wavelength SEDs, typical values are $\delta = 16$ and $B = 0.03$ Gauss. This is a relatively weak magnetic field strength. In the EC models the magnetic fields are 4 orders of magnitude greater (Sikora et al. 1997).

This derivation shows that measurements at one wavelength do not allow to determine the basic jet parameters of the SSC model. Multi-wavelength measurements at many epochs are necessary to provide proper constraints for the model calculations. This includes FIR observations for a good definition of the synchrotron peak.

4. 3C 279 FIR POLARIZATION RESULTS

The motivation for the FIR polarization measurements of 3C 279 were the following:

- Polarized emission by the synchrotron source is expected, in particular as the synchrotron peak lies in or close to the FIR wavelength regime.
- 3C 279 had shown a γ-ray flare in January 1996 (Wehrle & Hartman 1996, Wehrle et al. 1998)

We measured 3C 279 at two epochs with the FIR polarimetric observation mode PHT51 (Klaas et al. 1999b) of ISOPHOT (Lemke et al. 1996) onboard the Infrared Space Observatory (Kessler et al. 1996) and could successfully measure polarization of this object in the FIR for the first time.

Our findings are the following:

- 1996-07-26:
  $P = 22.8 \pm 1.6$ %, $\Theta = 77.9 \pm 3.0$ deg
- 1997-06-20:
  $P \sim 6.5 \pm 1.5$ %, $\Theta = 98.0 \pm 5.6$ deg
- The total 170 μm flux is 2.5 Jy at both epochs

The polarization of the first epoch is roughly aligned with the mas radio jet (Fig. 1). This means the following jet-polarization geometry:

- Magnetic field direction $\perp$ base of jet (Figure 1)
- FIR polarization $\perp$ radio polarization (c.f. Cawthorne & Gabuzda 1996)
- FIR polarization $\parallel$ optical (Gabuzda & Sitko 1994) and submm (Stevens et al. 1996) polarization

5. INTERPRETATION OF 3C 279 POLARIZATION

The high polarization degree at the first epoch argues for optically thin synchrotron emission, cf. Table 1. Also at the second epoch the emission was more likely optically thin.

The polarization varies drastically within one year. This implies that the FIR emission area is very compact and hence very likely close to the core. In the contrary the radio emission comes from the outer knots.

Table 1. Polarization degree for optically thin and optically thick synchrotron emission depending on the exponent of the electron energy γ_b (after Pacholczyk 1970).

Function	$\log_{10}(\gamma_b)$ 1	2	3	4	5
P(thin)	0.69	0.75	0.79	0.82	0.84
P(thick)	0.12	0.10	0.08	0.07	0.06

6. INTERPRETATION OF 3C 279 FIR POLARIZATION VARIABILITY

Nartallo et al. (1998) had found a correlation between the polarization degree and the total flux at 1.1 mm and explained that by plane shocks enhancing both the flux and the perpendicular magnetic field. Our results do not confirm this picture for the FIR, as the total FIR flux was equal both for the high and the low polarization stage. We note, however, that the 170 μm flux was not constant over the period from July 96 to June 97 and went through a minimum in December 1998 (Haas et al. 1998).

Our interpretation favours geometry effects as the explanation for the variable polarization. As can be seen from the spatially resolved VLBI radio polarization maps, the magnetic field is re-oriented several times along the jet and the radio polarization flips between the stationary knots (Leppänen et al. 1995).

There is observational evidence that new knots form in the cores of these superluminal radio sources following strong γ-ray outbursts (e.g. Pohl et al. 1995). Following the γ-ray flare of 3C 279 in January 1996, a new knot formed in the core region emitting the bulk of the FIR emission. In July 1996 there was still a highly ordered magnetic field perpendicular to the jet axis which produced the high polarization degree of the FIR radiation. When travelling out a re-orientation and disordering of the magnetic field happened resulting in a relatively small effective FIR polarization degree and a less good alignment with the jet axis.

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