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Infrared polarisation of blazar 3C454.3 in flare

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The blazar 3C454.3 underwent a flaring episode in July 2007 during which it was detected in high energy gamma-rays by AGILE. We report on infrared polarimetric observations taken a few days after the last AGILE observation. The source was still in flare with a near-infrared flux more than ten times brighter than during quiescence periods. The infrared light was significantly polarised at the level of a few percent, comparable to previous measurements from radio to optical. No variability is detected on hour timescales but the polarisation amplitude changed from 5.3% to 2.7% between two consecutive nights without the flux or the polarisation angle changing much. Much remains to be done to characterize visible light polarisation variability in blazars and link it to the multiwavelength behaviour, notably in radio.

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1. Introduction

3C454.3 is a flat spectrum radio quasar ($z = 0.86$), one of the brightest radio sources and one of the most active gamma-ray emitters, detected several times by EGRET in the 1990s. Optical activity and a gamma-ray detection by AGILE were reported in July 2007. The gamma-ray flux of 3 10^{-6} ph cm^{-2} s^{-1} (>100 MeV) was historically high during the AGILE observations (July 24-30, Vercellone et al. 2008). The R band magnitude reached 13, compared to the 2005 historical high of 12, but well beyond its 'quiescence' level at $R \approx 16$ (Villata et al., 2006). Observations of 3C454.3 were obtained on the nights of August 1 and 2, 2007 with the *New Technology Telescope* of the *European Southern Observatory* in infrared polarimetric setup. The results are reported here.

2. Observations and Reduction

Linear polarimetry is measured by inserting a Wollaston prism which splits the incoming light into two images with perpendicular polarisation. After proper masking, the two images are simultaneously recorded by the infrared camera *SOFI*. The instrument is then rotated by 45° and a second exposure taken (there is no half-wave plate). The two exposures contain images at polarisation angles $\theta = 0°$, 45°, 90° and 135° which then allow the determination of the Stokes Q and U parameters. Here, all of the polarimetric measurements were taken with the K_s filter (λ_c=2.16 μm).

2.1 Instrumental polarisation

There is a significant instrumental polarisation using this setup, notably because of the difference in the transmission for the ordinary and extraordinary beams. This transmission can be corrected for by combining exposures taken 90° apart, which flip the light paths of the θ and θ+90° beams. However, a setup error led to exposures taken at $\theta = 0°$, 22.°5, 45°, 67.°5 instead of the exposures at 0°, 45°, 90°, 135° that would have allowed a straightforward correction. Fortunately, these measurements still enable to cancel the effect of the transmission coefficient, albeit in a circonvoluted way. If I_θ is the source intensity recorded with the polariser at an angle θ, T_θ the transmission coefficient, I_p (resp. I_0) the linearly polarised (resp. unpolarised) source intensity and θ_p its angle then

$$I_\theta = \frac{I_0}{2} + I_p \cos^2(\theta - \theta_p) \quad \text{and} \quad I_{\theta+90^\circ} = T_\theta \left[\frac{I_0}{2} + I_p \sin^2(\theta - \theta_p)\right], \tag{2.1}$$

where $I = I_0 + I_p$ is the total intensity of the object. Since the Stokes coefficients are derived from a difference between orthogonal polarisations, $T_\theta \neq 1$ will lead to a measured polarisation even if $I_p = 0$. The data can be modeled by using Eq. 2.1 to find the values of I, q, u and T by least-square fitting, assuming the transmission coefficient is independent of θ and constant during the measurement time interval. Alternatively, under the same assumptions, then the ratios

$$R_\theta = \frac{\sqrt{I_\theta I_{\theta+22.^\circ5+90^\circ}} - \sqrt{I_{\theta+90^\circ} I_{\theta+22.^\circ5}}}{\sqrt{I_\theta I_{\theta+22.^\circ5+90^\circ}} + \sqrt{I_{\theta+90^\circ} I_{\theta+22.^\circ5}}} \tag{2.2}$$

will be independent of T. Taking ratios cancels flat fielding errors. For $I_p/I_0 \ll 1$ the ratios are linear combinations of the reduced Stokes parameters q and u such that

$$R_0 \approx (1 - \sqrt{2}/2)q - (\sqrt{2}/2)u \quad \text{and} \quad R_{45} \approx (\sqrt{2}/2)q + (1 - \sqrt{2}/2)u. \tag{2.3}$$

and

$$p \approx \left(\frac{4}{2-\sqrt{2}}\right)^{1/2} \left(R_0^2+R_{45}^2\right)^{1/2} \quad \text{and} \quad \theta_p \approx \frac{1}{2}\left[\operatorname{atan}\left(\frac{R_{45}}{R_0}\right) - 67.^\circ 5\right] \tag{2.4}$$

The results from the two methods (least-square fitting and ratios) described above were in very good agreement.

2.2 Data reduction

A series of 180, 3 second exposures were obtained with *SOFI* between MJD 54314.321 and 54314.404 at angles $\theta = 0^\circ$, $22.^\circ5$, 45°, $67.^\circ5$. The object position was jittered on the chip at five different locations before moving to the next angle. The ordinary and extraordinary beams in each exposure were independently flat-fielded as recommended in Wolf et al. (2002). The sky background was removed by using the jittered exposures as described in Lidman et al. (2002). Aperture photometry was performed using a 15 pixel radius, adapted to the seeing conditions. The polarimetric measurements were checked to be independent of the chosen aperture. The photometry from consecutive exposures taken at the same angle was then combined. The reduced Stokes parameters q and u were derived by using the methods described in §2.1. This gives 180 / 5 jitter positions / 4 angle = 9 measurements for each parameter for the first night. For the second night, 280 exposures were taken between MJD 54315.296 and 54315.411, yielding 14 measurements of the Stokes parameters. In addition, a single photometric measurement in the J, H and K_s band was obtained for both nights.

2.3 Polarimetric standards

The unpolarised standard WD2359-434 was observed on both nights and reduced as described above giving $q = -0.2 \pm 0.9\%$ and $u = 0.6 \pm 0.9\%$ for night 1 ($q = -0.6 \pm 0.9\%$, $u = 0.3 \pm 0.9\%$ for night 2). The unpolarised WD1620-394 gave $q = -1.9 \pm 0.6\%$ and $u = -0.4 \pm 0.6\%$ for night 1 ($q = -0.6 \pm 0.6\%$, $u = -1.1 \pm 0.6\%$ for night 2). Hence, no significant polarisation is found in both cases and the procedure enables a correction of the instrumental polarisation. Infrared polarised standards are very difficult to come by and very bright. Three were observed by defocusing the telescope but reliable photometry could not be obtained. Therefore, no angle correction could be applied to the data.

3. Results

Polarimetry was obtained for 3C454.3 and for the nearby star situated ≈ 14" NNE of the blazar. This star is bright (K=11.241, star 13 in González-Pérez et al. 2001) and serves as a useful check. The ordinary and extraordinary beam fluxes of the polarimetric observations were added for each exposure and differential photometry was performed between the two objects. The lightcurve, plotted in Figure 1, shows there was no intrinsic variability within each night. However, 3C454.3 was slightly brighter on August 2. The (single) photometric measurements gave $J = 11.791 \pm 0.02$, $H = 10.694 \pm 0.02$, $K_s = 10.010 \pm 0.02$ for August 1, and $J = 11.706 \pm 0.02$, $H = 10.655 \pm 0.02$, $Ks = 9.980 \pm 0.02$ on August 2. The fluxes are more than 10 times brighter than the 2MASS measurements. The photometry suggests the spectral energy distribution peaked in near infrared (see Figure 2).

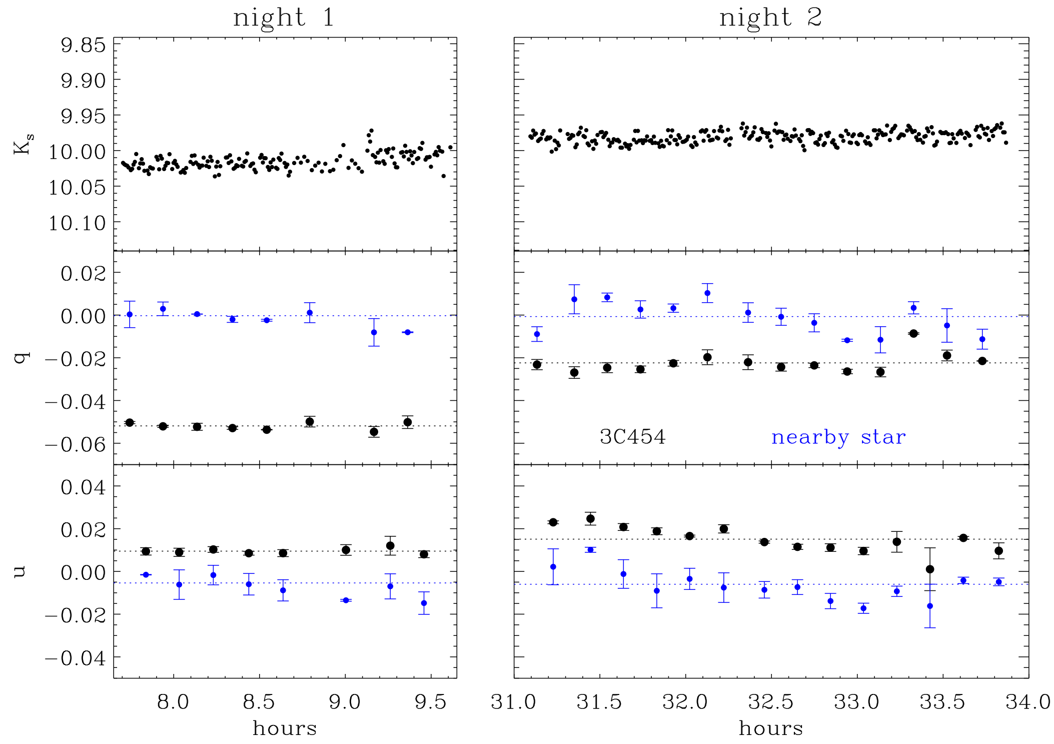

Figure 1: K_s lightcurve for 3C454.3 obtained by differential photometry with the nearby star (top), together with the reduced Stokes q (middle) and u (bottom) lightcurves for both objects. The reference time is MJD 54314.

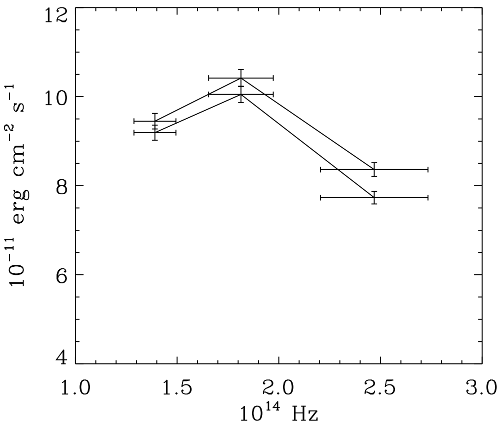

Figure 2: JHK_s spectral energy distribution for 3C454.3 on Aug. 1 & 2, 2007 (νF_ν in erg cm^{-2} s^{-1}).

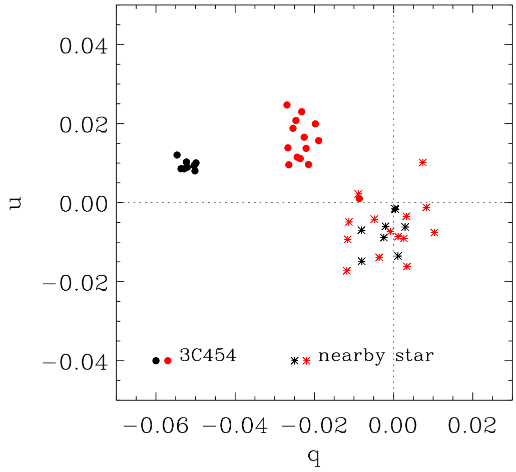

Figure 3: Same data as in Fig. 1 but plotted in the (q,u) plane. Data obtained on August 1 (resp. August 2) are in black (resp. red). The star has a low level of polarisation, compatible with zero. On the other hand, the K_s polarisation of 3C454.3 is significant and changes from one night to the other.

The polarisation lightcurves are also shown in Fig. 1 for both 3C454.3 and the nearby star. The polarisation is consistent with being constant within each night. There is a hint of a decrease with time of u in 3C454.3 during the second night but an instrumental effect cannot be ruled out as a similar trend may be apparent in the u lightcurve of the nearby star (albeit with poorer accuracy). The polarisation properties of the nearby star are consistent from one night to the other and compatible with zero polarisation, as expected from a star at a high galactic latitude. On the other hand, there is a significant change in the polarisation of 3C454.3 between the two nights. This is clearly seen in Figure 3 where the data is plotted in the (q,u) plane. The mean values for each night are:

August 1, 2007	3C454.3	$q = -5.19 \pm 0.17\%$	$u = +0.95 \pm 0.17\%$
August 2, 2007	3C454.3	$q = -2.24 \pm 0.17\%$	$u = +1.51 \pm 0.17\%$
August 1, 2007	nearby star	$q = +0.03 \pm 0.31\%$	$u = -0.54 \pm 0.29\%$
August 2, 2007	nearby star	$q = +0.07 \pm 0.31\%$	$u = -0.60 \pm 0.31\%$

The polarisation amplitude of 3C454.3 changes significantly between the two nights from $p \approx 5.3\%$ to $p \approx 2.7\%$ whereas the (uncalibrated) polarisation angle is more constant, moving from $\theta_p \approx 85^\circ$ to $\theta_p \approx 73^\circ$.

4. Discussion

The level of near-infrared emission observed at the *NTT* fits in very well on the spectral energy distribution reported by Ghisellini et al. (2007), showing fluxes recorded between July 24 and 29.

The NTT data suggest the synchrotron emission peaked at near-infrared frequencies on August 1 and 2. The flux variability was small but the dataset has a limited timespan. This contrasts with observations of blue (TeV) blazars which display strong variability on sub-hour timescales in X-rays, on the high frequency side of the synchrotron bump. This is likely due to the shorter cooling timescale of X-ray emitting electrons.

The K_s band polarisation amplitude is typical of the values reported in the past in radio or optical (Visvanathan, 1973; Moore & Stockman, 1981; Mead et al., 1990; Impey et al., 2000). It is rather smaller than the maximum amplitudes of 20-30% that have been observed at times in some blazars (Angel & Stockman, 1980; Sitko et al., 1985), excluding that a single optically thin zone with a highly homogeneous magnetic field dominates the emission in 3C454.3. There does not seem to be a difference with quiescent periods: for instance, an I band value of 5% with θ_p=80–120° is reported by Smith et al. (1988) when 3C454.3 was at $R = 16.02$. If changes in the Doppler boost cause variability, as proposed for 3C454.3 by Ghisellini et al. (2007), then light aberration might more readily modify the polarisation angle than the polarisation fraction between quiescence and flares. A measurement by Mead et al. (1990) was consistent with a wavelength independent $p = 3.8\%$ and $\theta_p \approx 160^\circ$ from optical to near-IR. There are few other values for the near-IR polarisation of 3C454.3 available in the litterature. Unlike some other sources, 3C454.3 is not known to have a preferred polarisation direction in optical/near-IR (Angel & Stockman, 1980).

In radio, the polarisation angle tends to be aligned or perpendicular to the jet direction. In 3C454.3, changes of 90° in polarisation angle have been seen (Cawthorne & Gabuzda, 1996; Gómez et al., 1999). The core polarisation is 2-4.6% at 4 GHz, while the VLBI components further away show up to 20% polarisation (Cawthorne & Gabuzda, 1996). This supports the localisation of the optical emission at the core. A comparison of the near-IR and mm polarisation properties would be of particular interest. Sikora et al. (2008) have advocated a model in which the optical and millimeter emission are co-spatial. The gamma-ray emission is due to external Compton upscattering of infrared dust emission by particles accelerated at a reconfinement shock 1 to 10 pc away from the black hole.

Variability in the polarisation fraction is common yet there is no clear, established relationship with intensity changes (Moore & Stockman, 1981; Moore et al., 1987; Smith et al., 1988; Ballard et al., 1990; Smith, 1996). Here, neither the flux nor the polarisation angle changed much. A rearrangement of the magnetic field structure would probably change both. Here, the almost constant angle suggests the magnetic field structure cannot have been altered much. Integrated emission from multiple components might explain the observations as the appearance or disappearance of a sub-structure, or a fluctuation in the index of the accelerated particle distribution, but this may be hard to reconcile with an intensity change of only ≈5%. Visible light polarisation maps on milliarcsecond scales that could be directly compared with the radio VLBI maps may become possible with advances in optical interferometry. Sources such 3C454.3, with $K \approx$10 during those observations, should be within the reach of the next generation of instruments.

Despite decades of studies, much remains to be done to characterize polarisation variability.

Previous studies have focused on large source samples, establishing polarisation as a hallmark of blazars and a signature of jet synchrotron emission, but at the expense of good sampling in time. Nowadays, well sampled optical polarisation lightcurves of blazars are becoming available as testified by the several studies shown at this conference. Such data enable a solid appraisal of *e.g.* any preferred polarisation orientation that could be compared with radio data on the jet morphology. These data also pave the way for the ambitious X-ray polarimeters that are being planned.

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