Optical Polarimetric Observations of TeV Blazars

Ulisses Barres de Almeida*, Tânia Dominici†, Zulema Abraham‡, Gabriel Franco§, Paula Chadwick*, Martin Ward*, Lowry McComb*, Catherine Boisson¶ and Jean-Philippe Lenain¶

*Department of Physics, University of Durham, England
†Laboratório Nacional de Astrofísica, LNA/MCT, Brasil
‡Departamento de Astronomia, Universidade de São Paulo, Brasil
§Universidade Federal de Minas Gerais, Belo Horizonte, Brasil
¶LUTH, Observatoire de Paris, CNRS, Université Paris Diderot, Meudon, France.

***Abstract*. We present the first results of an ongoing long-term project for the optical polarimetric observations of several VHE blazar jets. The observations are conducted at the Laboratório Nacional de Astrofísica, in Brazil, in coordination with observations by the H.E.S.S. experiment and the publicly available schedules of the Fermi/LAT telescope. The aim of the project is to generate a population database of the polarisation properties of HE-emitting jets and provide multi-wavelength information necessary to understand the origin of the gamma-ray emission. The overall results of a campaign on PKS 2155-304 are presented to illustrate the importance of polarimetric data on the study of extragalactic jets.**

***Keywords*: Extragalactic jets, optical polarimetry, TeV blazars.**

I. Introduction

Blazars are radio-loud active galactic nuclei (AGN) characterised by intense brightness variations on short timescales and by presenting on average a higher polarization degree than other classes of AGNs [1]; Their non-thermal continuum emission extends up to TeV energies, due to the radiation Doppler boost resulting from the geometrical alignment of their relativistic jets to the line of sight. The sub-class of high-energy peaked BL Lacs (HBLs) forms a preferential group of VHE emitters [11], with the majority of the AGN sources detected at the TeV energies to date belonging to this class[1].

The SED of blazars is composed of two broad features, the first peaking at X-ray energies (for the HBLs), attributed to synchrotron emission from energetic electrons, and the other, peaking around GeV energies, believed to result from the inverse-Compton scattering of lower energy photons by this same population of particles (synchrotron self-Compton or external Compton models, cf. [22] and [31]). In this leptonic scenario, the temporal variability of these two photon populations is expected to be closely related, in a way that can be directly probed by multi-wavelength (MWL) observations. The details of such correlations are key to understanding the radiative mechanisms, the dynamics and location of particle acceleration in the jets.

Several studies have been successful in establishing correlations between the X-ray and the gamma-ray emission (e.g., [20]), but the searches for a correlation between the optical and high energies (HE) have given a less well defined picture (see [4]), possibly the result of confusion from the optical observations, where emission from multiple regions in the jet can be contributing to the total flux. Nevertheless there is an established (if yet unclear in its details) connection between the high-energy and optical emissions, with a number of recent observations of TeV high states being accompanied by optical activity, resulting in at least two source discoveries at VHE due to optical high-state triggers (e.g. [5] and [6]).

The natural polarization of the synchrotron radiation justifies the preference for the use of polarimetric observations to the study of particle acceleration and emission mechanisms in AGN jets, because it can directly trace the activity of the young, most energetic electron populations in the source, which are expected to be the source of the high-energy photons. Thus, the establishment of a relation between the optical polarized flux and the gamma-ray emission would allow the imposition of the necessary temporal constraints to decide between competing physical models regarding the particle and photon populations responsible for the high-energy emission from blazars [23]. Additionally, the study of the polarization angle can provide information about the intensity and orientation of the magnetic field of the emitting region, which can help the understanding of the dynamics and location of the sites of particle acceleration in the source [24].

II. LNA Optical Polarimetric Monitoring Program for Gamma-Ray Blazars

In this paper we are going to show the first results of a long-term, 3 year program for the optical polarimetric monitoring of VHE-emitting blazars. The program is being pursued at the Laboratório Nacional de Astrofísica (LNA), operated by the Ministry of Science and Technology (MCT) of Brazil. Observations are conducted at the Pico dos Dias Observatory (OPD), at an altitude of

[1]For a periodically updated catalogue of VHE gamma-ray AGN sources see http://tevcat.uchicago.edu/

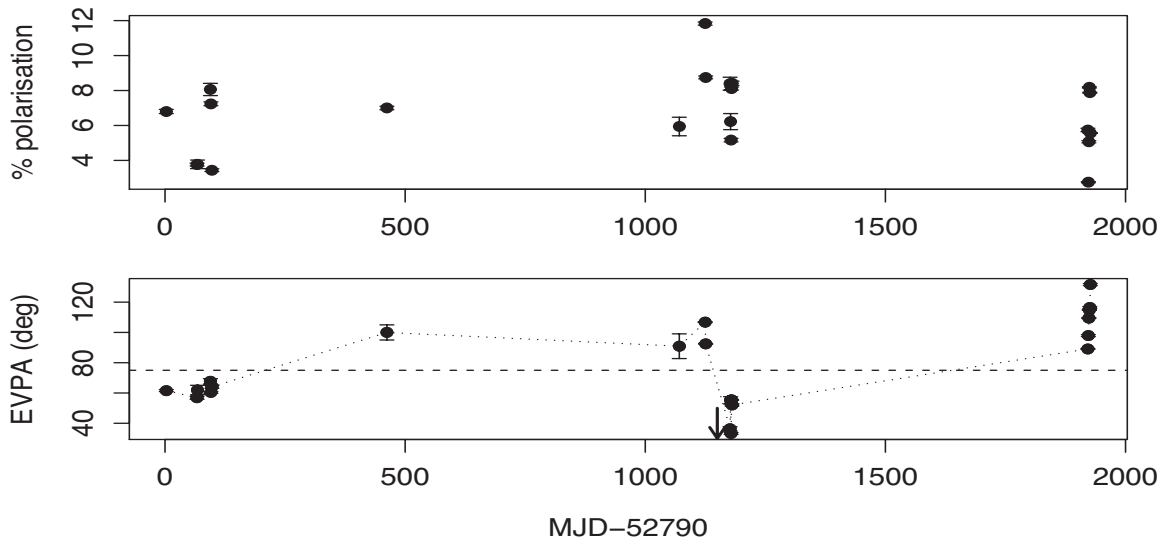

Fig. 1: Long term behaviour of R-band polarization for PKS 2155-304. The top panel presents the variation in the polarization degree. The bottom panel shows the correspondent polarization vector rotation. The vertical arrow indicates the time of the July 2006 large TeV flare [3], and the dashed line indicates the VLBI jet axis orientation [27]. The dotted line is only a guide to the eye. Data from 2003-2006 is from [12].

1800 m, using the polarimetric drawer IAGPOL ([21] [25]), coupled to a CCD camera operating in the V, R and I bands, producing contemporaneous multiband data. The polarimeter provides two simultaneous, orthogonally polarized images of the source, allowing for observations to be carried out under non-photometric conditions and for automatic correction of the sky polarization. The temporal resolution of the observations is limited by the integration time of the 8 different positions of the retarder plate, which amounts to a minimum of $\sim$ 20 min in the fastest filters for a typical strong source. The data analysis is done with the specially developed software PCCDPACK [25], operating on the IRAF platform.

The monitoring program has started this year, following a series of independent campaigns conducted since 2003 by Dominici et al. ([12], [13] and [14] for previous publications). The main objective of the program is to create a significant population database for the study of the polarization properties of gamma-ray blazars by means of regular observations of *all known* southern VHE blazars. Many of these sources are primary targets for the H.E.S.S. experiment, and part of our scheduling is done in coordination with H.E.S.S. Regular participation in coordinated MWL campaigns is also a main goal of the program, aiming to complement the current international efforts with important polarimetric data that is usually missing in these campaigns.

The results to be presented here concentrate on observations of the blazar PKS 2155-304 performed in September 2008, simultaneously with high-energy multiwavelength campaigns. They serve to illustrate the scope and activities of the program, presently unique to our knowledge in its length and breadth.

III. Some results from MWL Campaigns on PKS 2155-304

The HBL PKS 2155-304 (z = 0.116) is the brightest and most active gamma-ray source of the southern hemisphere [10], and has been studied in great detail in all wavelengths (e.g. [4], [32], [15]). In the VHE domain it has recently undergone episodes of extreme variability: in July 2006 the H.E.S.S. telescopes registered a peak flux of up to 70$\times$ the source quiescent level emission and flux doubling times of $\sim$ 2 min [3]. Theoretical efforts to understand these extreme episodes led, in fact, to a scenario in which the emission seems to come from small, high-Doppler factor (Γ) regions, located further away from the AGN core (more than $\sim 100R_S$), and thus closer to the radio and optical regions than once thought (see [9], [17], [19]), which strengthens the prospects for and the necessity of simultaneous, good temporal resolution MWL observations to test the models.

In radio, the source has been extensively studied both with single dish and interferometric measurements (e.g.[26]). VLBI observations by Piner & Edwards ([27] and [28]) have revealed the presence of a variable and polarized (3 - 10%) radio core. Downstream from it follows a mildly relativistic ($\Gamma \sim 5$) jet, closely aligned to the line of sight ($\sim 4^o$), that suffer several bends at the pc to kpc scales, as it looses momentum after propagation. Clockwise rotations of the jet position angle of about $\sim 10^o$ were registered in the 3 years separating the two interferometric observations. The polarization angle in the core is in close alignment with the inner jet axis (P.A.

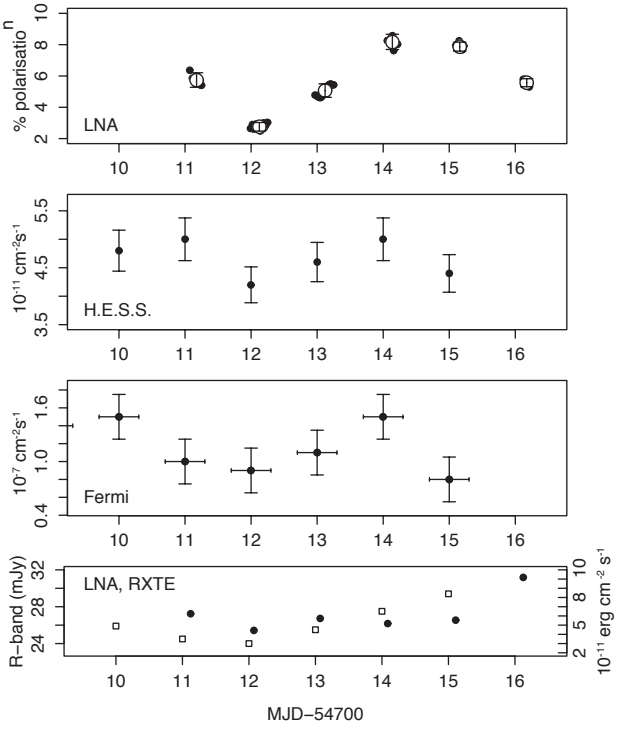

Fig. 2: Lightcurves for the 2008 MWL campaign on PKS2155-304. From top to bottom: LNA polarisation degree for the R-band; HESS VHE flux in units of 10^{-11}cm^{-2}s^{-1}; Fermi gamma-ray flux in units of 10^{-7}cm^{-2}s^{-1}; total R-band LNA optical flux in mJy (filled circles) and RXTE/SWIFT X-ray flux in units of 10^{-11}erg cm^{-2}s^{-1} (open squares).

$\sim 80^o$), suggesting the presence of compressed magnetic fields transverse to the flow, indicative of shocks.

Optical polarization measurements have been conducted for this source, but only rarely contemporaneously with high energy observations. Typical values of optical polarization are similar to those registered for the GHz radio core [27], and seem to decrease with wavelength. As with the total optical flux, the polarization degree is also variable, but usually presents sharper variations and shorter timescales, which is expected if we interpret these measurements to be tracing recently shocked particle populations. Several campaigns have also shown the electric vector position angle (EVPA) to rotate on short, intra-night timescales [7].

PKS 2155-304 has been first observed in polarimetric mode at the LNA observatory by Dominici et al., in a number of campaigns from 2003 to 2006 [12]; the 2006 campaign is particularly interesting, for it takes place shortly after the HESS VHE flare [3], between the 22^{nd} and 27^{th} of August 2006, while the source was still in a relatively high-state. In August 2008 (MJD 54711-16) the source was observed as part of our long-term program simultaneously with a H.E.S.S./FERMI coordinated campaign[2] [2], providing for the first time optical polarimetric information for blazars truly simultaneously with gamma-ray observations.

Figure 1 shows the long-term polarization degree and position angle light-curves for the 2008 observations, plus results from 2003-2006 from a previous work by Dominici et al. [12]. Regarding the polarization degree one can see that its values during all periods are confined to the historical limits determined by previous measurements, between 2 and 10%, also of the order of the polarization of the jet radio core. A near-to-historical maximum of 12% was registered in 2006, about a month before the intense VHE flare. Shorter scale variability was present within all periods, even when the total optical flux wasn't significantly variable; from the amplitude of such variations it is clear that the source variability is dominated by short-timescale (intra to inter-night) events. High optical duty-cycles in all probed timescales, from years to hours, are consistent with data in [30] and [7].

The polarization position angle also presented significant rotation on multiple timescales: Due to the sparsity of the observational coverage, it is difficult to define a preferential long-timescale direction or rate of rotation, and one can see events working in both senses. It is nevertheless notable that the most dramatic rotation episodes occurred between June and August 2006, when the source underwent substantial counter-clockwise rotation of $\sim 60^o$, contemporaneously with the TeV flare registered by H.E.S.S. This event is briefly preceded by a maximum in the polarization degree, and both events together are clear signature for recent particle acceleration episodes, which could be caused by injection of new material in the jet or new shocks that would also work to re-organize the magnetic field in the region. Both events are known to result in emission of high-energy photons and the polarization data can provide unique information on the dynamics underlying such events.

The main advantage of polarimetric observations over simple photometry is that in the former we are looking more directly at the newly accelerate particle population, which are the responsible for the highest energy emissions and the most extreme episodes of variability. One such example of this is the analysis of micro-variability in the 2008 campaign of PKS 2155-304, which consistently presented higher duty cycles and shorter variability timescales[3] for the polarized emission, by up to a factor of 2 in relation to the total optical flux. In fact, Dominici et al. [12] found a duty cycle of polarization of 91.3% in the active state of 2006.

Variability features which wouldn't be noticeable in the total optical flux, or would appear delayed or

[2]See details of the coordinated campaign on the FERMI/LAT public webpage http://fermi.gsfc.nasa.gov/ssc/resources/multi/reporting/list.php

[3]Shortest variability timescales for polarised emission were of ~ 30 min, of the order of the temporal resolution of the observations.

smoothed in the light-curves due to contamination from emission outside the zone of production of the HE-VHE photons, show more clearly in the polarized light-curves and allow a better study of the emitting regions alone. Figure 2 shows the contemporaneous HESS/Fermi/LNA light-curves for the 2008 campaign, where despite the quiescent state of the source and consequent marginal variability in the high energies, clear variability can be seen in the LNA data which follows the features seen in gamma-rays. If we compare these datasets to the RXTE and optical light-curves published by the HESS and Fermi collaborations [2] one can clearly note that the polarized emission traces the IC emission in a way that the optical and X-ray emission (which appear correlated) cannot. This fact can be understood from the fact that both optical and X-ray quiescent emission would originate from larger zones than the gamma-rays [18].

IV. Development of the Program

We have presented a global view of the very first result of our polarimetric monitoring program of blazars, that illustrate the unique kind of contribution given by optical polarimetry to MWL observations. The project, which was granted a total of 90 nights distributed over 3 years, will regularly observe bright VHE-emitting blazars, looking for singling out population characteristics of these objects and to provide complementary coverage for observational campaigns, specially during active states, where the source energetics become dominated by the HE emission and one has the opportunity to better constrain the particle acceleration and radiation models. The program is keen to collaborate in multi-wavelength campaigns and contact for coordinated campaigns are welcome.

Acknowledgements

U.Barres de Almeida acknowledges a PhD scholarship from the CAPES Foundation, Ministry of Education of Brazil. The authors thank the H.E.S.S. collaboration for sharing the observation schedules associated of some of the observations presented here and regarding the long-term project. We also thank the staff and technicians of LNA/MCT for support on conducting the observations and taking the data.

References

[1] J.R.P. Angel & H.S. Stockman *Ann. Rev. Astron. & Astroph.* 18, 321 (1980)
[2] F. Aharonian et al. *Astroph. Journal* 696, L150 (2009)
[3] F. Aharonian et al. *Astroph. Journal*, 664, L71 (2007).
[4] F. Aharonian et al. *Astron. & Astroph.* 442, 895 (2005)
[5] J. Albert et al. *Astron. Journal* 648, L 105 (2006)
[6] J. Albert et al. *Astroph. Journal* 71, 664L (2007)
[7] I. Andruchow, G.E. Romero &S.A. Cellone *Astron. & Astroph.* 442, 97 (2005)
[8] U. Barres de Almeida, et al. *Proceedings of the Workshop on Blazar Variability across the Electromagnetic Spectrum*, Palaiseau, France. Published online at pos.sissa.it, p.27 (2008)
[9] M.C. Begelman, A.C. Fabian & M.J. Rees *Month. Not. Royal Astron. Soc.* 384, 19 (2008)
[10] P.M. Chadwick et al. (1999)
[11] L. Costamante & G. Ghisellini *Astron. Astroph.* 384, 56 (2002)
[12] T.P. Dominici, et al. *Proceedings of the Workshop on Blazar Variability across the Electromagnetic Spectrum*, Palaiseau, France. Published online at pos.sissa.it, p.35 (2008)
[13] T.P. Dominici, Z. Abraham & A.L. Galo *Astron. Astroph.* 460, 665 (2006)
[14] T.P. Dominici, et al. *Astron. Journal* 128, 47 (2004)
[15] R. Edelson et al. *Astroph. Journal* 438, 120 (1995)
[16]
[17] G. Ghisellini & F. Tavecchio *Month. Not. Royal Astron. Soc.* 386, 28 (2008)
[18] B. Giebels et al. *Astroph. Journal* 571, 763 (2002)
[19] K. Katarzýnski et al. *Month. Not. Royal Astronon. Soc.* 390, 371 (2008)
[20] H. Krawczynski, et al. *Astroph. Journal* 601, 151 (2004)
[21] A.M. Magalhães et al. *ASP Conf. Series* 97, 118 (1996)
[22] L. Maraschi, G. Ghisellini & A. Celotti *Astroph. Journal* 395, L5 (1992)
[23] A. Marscher et al. *Nature* 452, 966 (2008)
[24] A. Marscher & S. Jorstad *The first GLAST Simposium*. AIP Conf Series 921 (2007)
[25] A. Pereyra *Ph.D. Thesis* IAG/USP (2000)
[26] J. Pesce et al. *Astroph. Journal* 486, 770 (1997)
[27] G. Pinner, N. Pant & P.G. Edwards *Astroph. Journal* 678, 64 (2008)
[28] B.G. Piner & P.G. Edwards *Astroph. Journal* 600, 115 (2004)
[29] G. Romero et al. (1995)
[30] G. Romero et al. (1999)
[31] M. Sikora, M.C. Begelman & M.Rees *Astroph. Journal* 421, 153 (1994)
[32] C.M. Urry et al. *Astroph. Journal* 486, 799 (1997)