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Variability and stability in optical blazar jets

The case of OJ287

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Abstract. OJ287 is a BL Lac object at redshift $z = 0.306$ that has shown double-peaked bursts at regular intervals of ∼ 12 yr during the last ∼ 40 yr. Due to this behavior, it has been suggested that OJ287 might host a close supermassive binary black hole. We present optical photopolarimetric monitoring data from 2005–2009, during which the latest double-peaked outburst occurred. We find a stable component in the optical jet: the optical polarization core. The optical polarization indicates that the magnetic field is oriented parallel to the jet. Using historical optical polarization data, we trace the evolution of the optical polarization core and find that it has showed a swing in the Stokes plane indicating a reorientation of the jet magnetic field. We also find that changes in the optical jet magnetic field seem tightly related to the double-peaked bursts. We use our findings as a new constraint on possible binary black hole models. Combining all available observations, we find that none of the proposed binary black bole models is able to fully explain the observations. We suggest a new approach to understanding OJ287 that is based on the assumption that changes in the jet magnetic field drive the regular outbursts.

Key words. BL Lacartea objects : individual : OJ287 – galaxies : jets

1. Introduction

Blazars are amongst the most violently variable sources in the Universe. According to the standard model (Urry & Padovani, 1995), blazars are AGN with a jet pointing almost directly towards the observer, the jet radiation is thus highly beamed and dominates the spectrum. Therefore, blazars are perfect laboratories to study variability and turbulence in AGN jets.

Blazars show variability on time scales from hours to decades, with partially extreme amplitudes (Ulrich et al., 1997; Valtaoja et al., 2000; Villforth et al., 2009). The radio structure of blazar jets consists of a so-called radio-core that does not move and blobs that appear to be ejected from the core and move away from it at apparently superluminal speeds (e.g. Jorstad et al., 2001). It is assumed that the core

Send offprint requests to: C. Villforth represents a standing shock front at the end of the collimination zone (Marscher, 2009). The highest energy photons are believed to originate close to the black hole, with x-ray and optical emission originating in the collimination zone (Marscher, 2009). Radio emission dominates further downstream.

This picture agrees rather well withy magneto-hydrodynamical simulations (Nakamura et al., 2001). Those simulations also indicate that the magnetic field is ordered in the collimination zone, building a toroidal magnetic field. At the end of the collimination zone, a standing shock front appears and further down the jet the toroidal jet magnetic field breaks up due to turbulences. This theoretical expectation seems to describe the observations in the jet of the nearby radio galaxy M87 rather well (Biretta et al., 1991; Junor et al., 1999; Asada et al., 2008).

Given the fact that most of the studies on blazar jets have been performed in the radio (e.g. Jorstad et al., 2001; Gabuzda, 2003), optical polarization studies can give new insights into the parts of blazar jets in which the optical emission originates (e.g. Hagen-Thorn, 1980; Holmes et al., 1984; Jannuzi et al., 1994; Gabuzda et al., 2006; Villforth et al., 2010a).

For our study, we choose OJ287, which is one of the best studied blazars. OJ287 has received a lot of attention as it has shown massive double-peaked outbursts approximately every 12 years during the last 40–100 years (Villforth et al., 2010a). It has been therefore been suggested that OJ287 hosts a close supermassive binary black hole (e.g. Sillanpää et al. , 1988; Lehto & Valtonen, 1996; Katz, 1997; Villata et al., 1998; Valtaoja et al., 2000; Valtonen et al., 2006; Valtonen, 2007; Valtonen et al., 2009). Our monitoring campaign covers the last double-peaked outburst observed in OJ287. We can therefore also use the data to constrain the binary black hole models proposed for OJ287.

2. Observations and data reduction

This study is based on the data published in (Villforth et al., 2010a). Information about observations and data reduction can be found in said paper. All data are also available on Vizier (Villforth et al., 2010b). A plot of the entire data is shown in Fig 1.

3. Using optical polarization data to trace the jet magnetic field

As can be seen in Fig. 1, the position angle of the optical polarization in OJ287 had a clear preferred value during our monitoring campaign. This is a behavior that is often observed in BL Lac objects (Jannuzi et al., 1994). This behaviour is possibly less prominent in Flat Spectrum Radio Quasars (FSRQs) (Angel & Stockman, 1980; Villforth et al., 2010a).

To study the origin of this preferred position angle, we study the properties of the entire polarimetric data set in the Stokes plane. It can be shown that there is a very clearly defined peak in the distributions of both Stokes parameters. Assuming that the peak is caused by a single source of polarized emission, the optical polarization core (OPC), we can subtract the OPC vectorially from all data points. We find that the alignment in position angle disappears. This means that the preferred position angle can be explained by a single source of polarized emission, the OPC. Note that distributions in the Stokes plane similar to the one observed in OJ287 are commonly observed in BL Lac objects (Jannuzi et al., 1994).

The emission of the OPC constitutes about 20% of the optical emission of OJ287 in a moderate state, assuming a degree of polarization of 80%. This is the maximum degree of polarization possible in synchrotron radiation. We can interpret this emission either as a sign of emission from a quiescent jet with a global magnetic field or as a sign of a standing shock front. In Villforth et al. (2010a) we argued that it is likely that the emission originates from a quiescent jet. This is also supported by the finding that the degree of polarization and total optical flux show no correlation (Villforth et al., 2010a). This finding is inconsistent with a model in which all polarized emission originates in shock fronts (Marscher & Gear, 1985). Therefore the quiescent jet hypothesis is favoured.

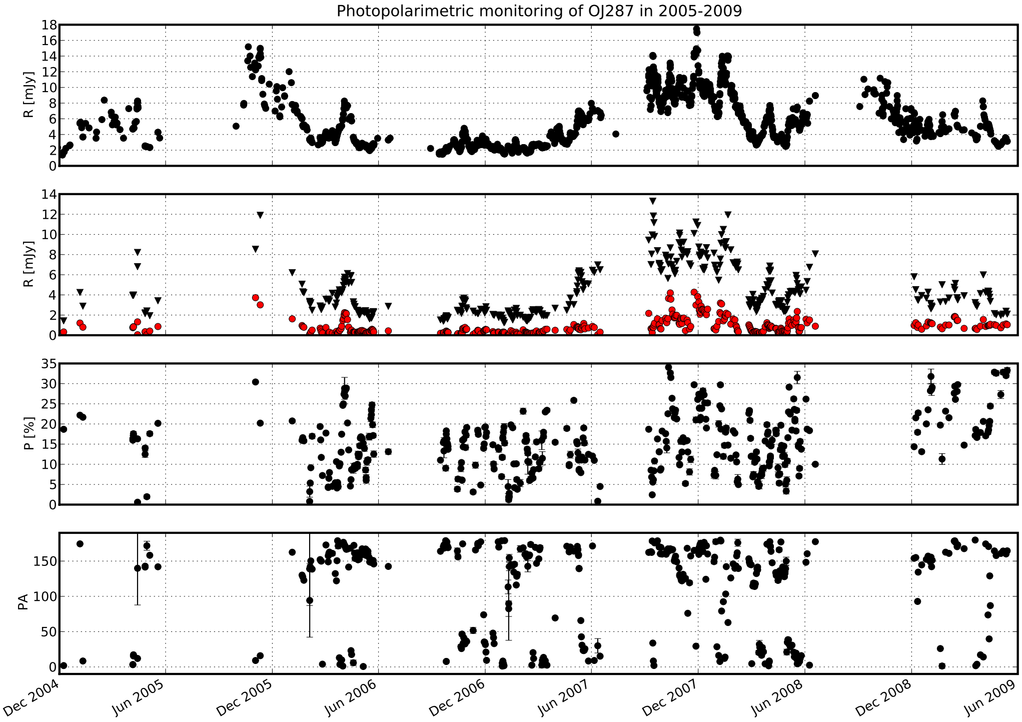

Fig. 1. Full photopolarimetric light-curve for OJ287 in 2005–2009. Panels show following values, from top to bottom: total flux; polarized (red circles) and unpolarized (black triangles) flux; degree of polarization; position angle.

Given above findings, it is of interest to understand the long term evolution of the optical polarization core.

We show a plot of the long term evolution of the optical polarization position angle in Fig. 2. Note that this data is combined from data sets in several filters. However, given that the differences between the position angle in the optical are at most on the order of a few degrees (Holmes et al., 1984), this should not affect our analysis.

We clearly see that the position angle changed its preferred direction, the changes in the alignment of the optical polarization seem to be tightly related to the outburst in optical flux.

4. Does OJ287 host a supermassive binary black hole?

Another open question is if OJ287 hosts a supermassive binary black hole. This has been suggested by several authors (e.g. Sillanpää et al. , 1988; Lehto & Valtonen, 1996; Katz, 1997; Villata et al., 1998; Valtaoja et al., 2000; Valtonen et al., 2006, 2009). See Villforth et al. (2010a) for a summary and description of all these models. Summarizing all available data, we find that none of the models is fully able to explain all the observations.

Given that our findings of the OPC are indicating strong changes in the jet magnetic field that are not consistent with any model based on a binary black hole, we suggest a new approach for OJ287 models.

We suggest that the changes in the jet magnetic field are causing the double peaked bursts. We suggest that resonance in the accre-

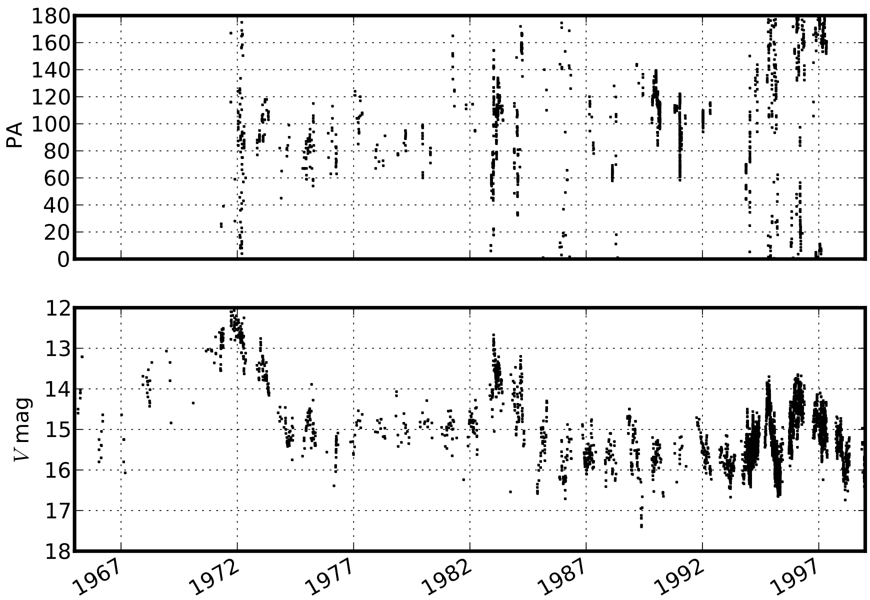

Fig. 2. Evolution of the optical position angle *PA* (upper panel) and and optical magnitude (lower panel) of OJ287 from ~ 1970 till the mid 1990s.

tion disk magnetic field is causing avalanche accretion of poloidal magnetic field lines, thereby changing the pitch angel of the toroidal jet magnetic field. Over time, the change in the pitch angle will change the apparent direction of the projected jet magnetic field, as observed in OJ287 (Villforth et al., 2010a).

5. Conclusions

Based on about three years of photopolarimetric monitoring of the blazar OJ287, we study the variability and stability of optical blazar jets. We also asses different binary black hole models that have been proposed to explain the regularly appearing double-peaked optical outbursts observed in OJ287.

We found a stable component in the optical polarization, the optical polarization core (OPC). We interpret this as the emission from the quiescent jet, the OPC can therefore be used to trace the jet magnetic field.

Using all available data, we find that none of the proposed binary black hole models is fully able to explain all the observations. Based on our finding of strong changes in the jet magnetic field, we suggest that the double-peaked outbursts observed in OJ287 are due to accretion of magnetic field, causing a change in the pitch angle. This is observed as an apparent change in the projected jet magnetic field.

Further observations will have to show if possible further outbursts can constrain models on OJ287. Continued long term photopolarimetric monitoring will be needed to achieve this goal. Till then, the case of OJ287 will remain a mystery.

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