The Multimessenger Chakra of Blazar Jets
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Multiwavelength monitoring of the nucleus in PBC J2333.9−2343: A giant radio galaxy with a Blazar-like core

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Abstract. We present an observational multiwavelength campaign during 2018–19 for PBC J2333.9−2343, a giant radio galaxy with a bright central core associated to a blazar nucleus, whose structure could be due to a significant jet reorientation. We report flux increases by a factor of two or more on timescales shorter than a month, resembling flaring events. The cross correlation between the NIR and optical bands shows quasi-simultaneous variations arising from the jet. The optical variability properties of PBC J2333.9−2343 are more comparable to a sample of blazars than to non-blazar AGN. The SED of the nucleus shows two peaks, with a derived jet angle of 3 degrees, also typical of a blazar. Therefore, we confirm the presence of a blazar-like core in the center of this galaxy.

Keywords. galaxies: active, galaxies: nuclei, galaxies: variability

1. Introduction

Under the Unified Model of Active Galactic Nuclei (AGN), the different types of AGN are attributed to orientation effects, with radio galaxies showing a pair of jets in the plane of the sky, and blazars are sources where one of the jets is pointing to the observer (Urry & Padovani 1995).

However, one of the things that was not taken into account in this model was the fact that galaxies evolve with time, and can go through different phases of nuclear and/or jet activity. Reactivation and jet reorientation of AGN can be observed in some Giant Radio Galaxies (GRG, Ishwara-Chandra & Saikia 1999), which have projected linear sizes larger than 0.7 Mpc from radio-lobe to radio-lobe, and can have spectral ages of 10^7-10^8 yr (Alexander & Leahy 1987). X-shaped radio galaxies (XRG) are another possible consequence of reactivation or jet reorientation reported in the literature (Gillone, Capetti, & Rossi 2016). Sources of this kind are therefore perfect laboratories to study intermittent activity and AGN evolution because these processes occur on accessible timescales (i.e., the changes can be observed in a few years).

PBC J2333.9−2343 is a GRG whose Very Large Array (VLA) radio map shows two jets with a linear size of 1.2 Mpc (Bassani et al. 2016). Observations at milliarcsecond scale with the Very Long Baseline Array (VLBA) show an optically thick compact core with an optically thin jet. Hernández-García et al. (2017) studied these and *XMM–Newton* data and proposed that a Blazar-like nucleus beamed at an angle < 6 degrees to the line of sight resides at the center of this GRG. Moreover, Bruni et al. (2020) presented a deep image with the Giant Metrewave Radio Telescope (GMRT) at 150 MHz showing a lack of emission between the lobes and the core region. A study of its variability on timescales of years in the optical, UV and X-rays was presented in Hernández-García et al. (2018). To further constrain the properties of this peculiar galaxy, we performed a multiwavelength monitoring of its nucleus in 2018–19.

2. Data

We performed two monitoring campaigns, the first one between July 2018 and January 2019, and the second one between April-August 2019. The following data were used for the variability analysis as well as for building the spectral energy distribution (SED):

• Radio observations with the Effelsberg-100m telescope with a cadence of once per month at frequencies 4.8, 8.5, 10.5, and 20.4 GHz. For the SED we also used data from the Very Long Baseline Array (VLBA) at 15 and 24 GHz, Very Large Array Sky Survey (VLASS) at 3 GHz, and the Rapid ASKAP Continuum Survey at 0.88 GHz.

• Simultaneous near infrared and optical photometry with SMARTS-1.3m. Two campaigns were organized, in 2018 with 3–4 days cadence, and in 2019 with daily cadence.

• Optical photometry with the Zwicky Transient Facility (ZTF) and the Asteroid Terrestrial-impact Last Alert System (ATLAS) with 3–4 days cadences.

• Simultaneous X-ray (0.5-10 keV) and UV (UVM2 filter) data with the Neil Gehrels *Swift* Observatory with weekly cadence.

• Gamma-ray data from the Fermi Large Area Telescope (LAT). We were not able to obtain a light curve because the source was not detected with signal-to-noise ratio > 3 in bins of length smaller than one year. A detection at a 6σ level results from integrating

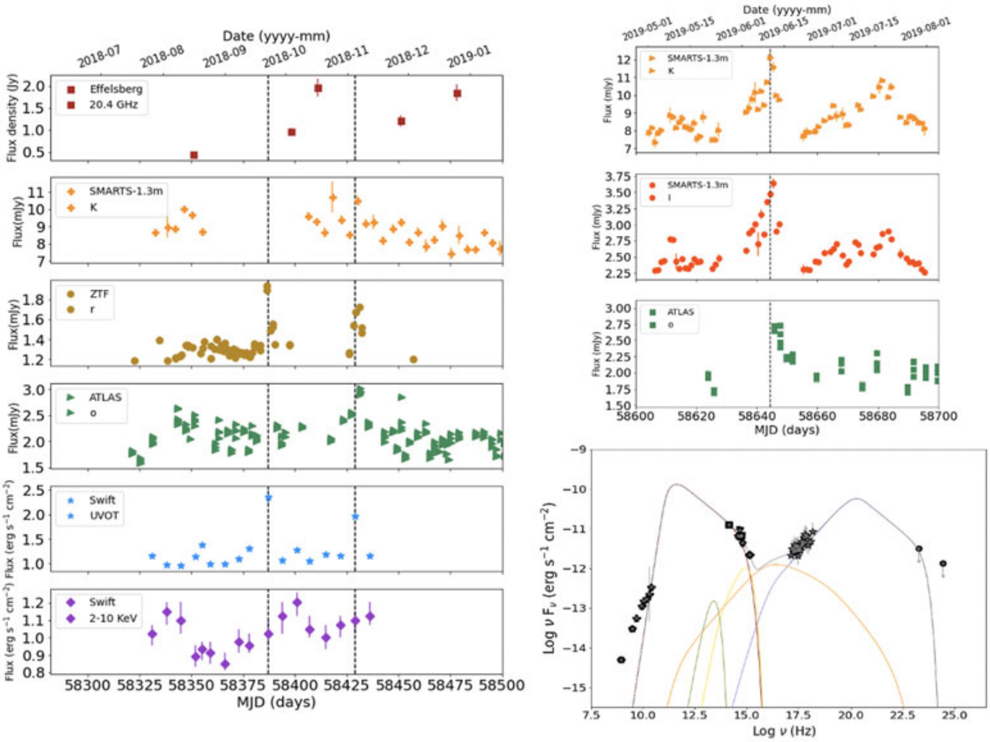

Figure 1. Left: Monitoring in 2018 from radio to X-rays (from top to bottom: Effelsberg, SMARTS-1.3m, ZTF, ATLAS, *Swift*/UVOT, and *Swift*/XRT); Upper-right: Monitoring in 2019 with SMARTS-1.3m and ATLAS; Lower-right: SED fitting using a leptonic model.

one year of data in the 0.1-300 GeV. For the SED we use upper limits in three equally spaced energy bins.

3. Main results

In Figure 1 (left) we plot the multiwavelength light curves for the monitoring in 2018, spanning between MJD=58320 (2018 July 21) and 58500 (2019 January 17). For simplicity and clarity, we plot only the most representative light curve per instrument. In the right panel we plot the monitoring performed between MJD=58600-58700 (April 27th–August 5th, 2019) with SMARTS-1.3m and ATLAS.

The results obtained from the analysis of these light curves and the multiwavelength data are presented in detail in Hernández-García et al. (2023), and here we report the main results:

• Variations are detected at all observed wavelengths at significance larger than 6σ, except at X-rays where variations are detected at 2σ within the four months.

• The observed flux variations show a flaring behaviour. Three events occurred during this monitoring and were detected at different frequencies.

• The cross-correlation between simultaneous optical/NIR shows a delay of 1.02 ± 1.45 days, i.e., suggesting that these variations occur quasi-simultaneously. The lack of delay is compatible with variations from the jet (see Hernández-García et al. 2023).

• When comparing the optical variability features with large samples of non-blazar AGN and blazars using samples from ALeRCE (Förster et al. 2021, Sánchez-Sáez et al. 2021), PBC J2333.9−2343 shows characteristics more similar to the blazar population.

• We constructed the SED using all the data described in Section 2, and it was then fitted with a single-zone leptonic model using the Jets SED modeler and fitting Tool (`JetSeT`, Tramacere 2020). The SED is presented in the right bottom panel of Fig.1, where two distinct peaks can be differentiated. The low energy peak is well fitted by synchrotron emission, while the high energy peak is dominated by External Compton (EC) from the dusty torus with some contribution from Synchrotron Self Compton (SSC). The jet angle is 3 degrees.

• We confirm the finding reported in Bruni et al. (2020) that there is no connection between the nucleus and the lobes using a deep RACS image.

• We confirm a very exceptional case of jet reorientation in PBC J2333.9−234, already proposed in Hernández-García et al. (2017), that shows a transformation from a GRG (with two lobes in the plane of the sky) to a blazar (with a jet pointing towards us).

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