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MWL study of OT 081 and other blazars on the border of categorization

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The blazar OT 081 was detected only once in the very-high-energy gamma-rays range, by MAGIC and H.E.S.S. telescopes. The multiwavelength (MWL) data collected in that single opportunity, and reported in a recently published paper [1], show a challenging theoretical interpretation because of the high Compton Dominance of the MWL SED. In the flaring episode presented in [1] moreover, the source, previously categorized as a BL Lac in several occasions, presents clearly characteristics of Flat Spectrum Radio Quasars. In this contribution we report the efforts in connecting the broadband model to the VLBI data, with two zone models that we also apply to a sample of candidate transitional blazars. The goal is to deepen our knowledge of blazars of controversial categorization.

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1. Introduction

Blazars are Active Galactic Nuclei (AGNs) powered by supermassive black holes (SMBH) and featuring a relativistic plasma jet pointed towards the Earth. Blazars present multi-wavelength (MWL) emission which extends from the radio to the gamma-ray band. Their broadband spectral energy distribution (SED), which consists in a two-bumped shape, constitutes a fingerprint which is used to categorize them depending on the peak position of the bumps. In particular, the bump which extends from radio to X-rays energies, is originated by synchrotron emission of charged particles in the accretion disk of the blazar, while the more energetic bump of the broadband SED, extending up to HE or VHE gamma-rays, has a more debated origin, which can be attributed to different processes and explained by different theoretical models. The identification of the emission mechanism of blazars can be often tricky, due to the difficulties in constraining one specific theoretical model, and also to the variability observed in many blazars, which can result in broadband SEDs which vary with time and flaring activities for the same blazar. In many cases, such changes in the broadband SEDs can make difficult to categorize a blazar and pose a challenge in the study of the emission mechanism: nevertheless they bring attention to possible evolutions of blazars and transitions to different categories and open the search to new ways to categorize such objects and understand their variable nature. A mainly used categorization divides blazars in two subclasses, BL Lac objects and Flat Spectrum Radio Quasars (FSRQs): the former ones do not present strong lines in their optical spectrum and their syncrothron peak is positioned at sub-mm band, while their high-energy peak is in the MeV band. In contrast, the latter ones exhibit evident lines in their optical spectra and their synchrotron peak is positioned in the UV–X-ray band, and the high-energy hump peaks in the GeV and sometimes even in the TeV band. The high-energy bump of blazars is defined by the gamma-ray emission: when simultaneous HE and VHE gamma-ray emission is observed, this can help significantly to choose between theoretical models. Nevertheless, this is a difficult task that depends on the success of MWL campaigns, in order to obtain simultaneous data in all the energy bands. Recently, thanks to the many MWL campaigns organized, the fast response to triggers for Fermi-LAT and other optical telescopes and to the higher sensitivity reached by Cherenkov telescopes, several blazars (expecially distant FSRQs) have been studied in MWL and some of them presented particular characteristics at the border between BL Lacs and FSRQs. In the following section we report some of those cases.

1.1 OT 081

In our recent paper [1], we have reported the discovery of VHE emission from the blazar OT 081, with MAGIC and H.E.S.S. telescopes, happened following up a Fermi-LAT alert of a flare in the HE gamma-ray range. This blazar was previously identified as a BL Lac object, but the MWL we collected during the VHE flaring activity in 2015 clearly point out to FSRQs characteristic. The high Compton Dominance of the SED, and the presence of lines in the optical spectra, made clear that OT 081 was behaving like a FSRQs in this occasion. The modeling we performed in [1] demonstrates the necessity of considering an external Compton component to explain the high-energy emission, which is typical of FSRQs. Nevertheless, this model can be further expanded considering the VLBI measurements taken around the flaring activity, making it possible to consider a two-zones scenario.

1.2 OP 313

OP 313 is a FSRQs located at redshift 0.997, currently the most distant blazar observed in the VHE gamma-ray range. In 2022, a flare in the HE gamma-ray range was observed by Fermi-LAT, and in the MWL picture of that flare, a clear correlation between optical and gamma-ray was observed. The study conducted in [2] identified two states of the source during this activity and modelled two broadband SEDs for the flaring and quiescent state. The broadband SED of the flaring state showed a lower Compton Dominance with respect to the quiescent state and characteristics typical of BL Lacs sources. Even if OP313 was firmly categorized as a FSRQs in literature, this behavior put it in the list of the so-called transitional blazars. In this case, the transition was attributed to an increase in the Doppler factor, because of the change of orientation of the emitting region. The dissipation region was located within the BLR during the quiescent state, and just outside the BLR during the flare. The corresponding decrease in the radiative cooling allowed the relativistic particles to reach higher energies, resulting in a shift in the synchrotron and IC component peaks. The question about considering OP 313 a changing-look blazar or a FSRQs that emerges as a BL Lac during high-flux states due to enhanced nonthermal emission was addressed in [3], where the authors including the measurements of optical spectra of the source and conclude that the source masquerades as a BL Lac source during high-flux states. Still the behaviour of the 2022 gamma-ray flare is very interesting and could be further investigated. VLBI observations can be very useful to investigate the morphology of the jet of OP 313 and furthermore, a paper in preparation from MAGIC and LST-1 collaboration will soon publish the broadband MWL data including VHE gamma-ray emission, and providing a more complete broadband dataset.

1.3 B2 1420+32

B2 1420+32 is a FSRQs discovered in the VHE gamma-ray range by MAGIC in 2020, during a bright flare in several energy bands [4]. The MWL campaign performed around that flare was very succesfull in describing the behaviour of the source in 4 different states of activity. The modeling confirmed the FSRQs nature and consisted in a leptonic scenario with an EC contribution from the dusty torus. Comparing to historical data, both low- and high-energy peaks shifted by at least two orders of magnitude in frequency, such a large shift being rare for a FSRQ object. Shifts of the peaks towards higher energies during high states is a behavior commonly observed in BL Lacs objects. The spectra are Compton dominated, which is typical for FSRQs. However, the dominance during the peak of the flare was just a factor of a few. The VLBI observations during this flare showed an emission of a superluminal radio knot contemporaneous with the high gamma-ray state scenario, which could be connected to the observed rotation of the EVPA angle. A similar association of VHE gamma-ray emission, with EVPA rotation, and VLBI component ejection has previously been suggested for another FSRQ, PKS 1510-089 [5], but also in other blazars [6–8]. In [9], the authors examine the MWL behaviour of the source between 2018 and 2020, claiming that it transitioned between BL Lac and FSRQ states multiple times. This study was accompained by measurements of the optical spectra and the transitions between FSRQ and BL Lac classifications are attributed to continuum variability. Also in [10] B2 1420+32 is considered a changing-looking blazar and several transitions from FSRQs to BL Lac are identified in the time period 2019-2023. In particular, the authors claim the evolution to be subdivided into five FSRQ states, nine transition

states, and four BL Lac states. Thier results suggest that the changing-looking variant is a distinct and significant phase closely tied to the evolution of blazars. In [11], the same study of the source is applied to a time range from 2018 to 2023, using in particular HE gamma-ray data, and again reporting about transitions from FSRQs characteristics to BL Lac and viceversa suggesting that the CL blazar represents a unique phase in the blazar sequence.

1.4 S4 0954+65

The blazar S4 0954+65 was discovered in the VHE gamma-ray range by MAGIC during an exceptionally high optical state in 2015. Precedently categorized as a BL Lac object, in this first study involving also VHE gamma-rays it showed a clear FSRQ behaviour. In [12], the broadband modeling of the flaring activity reveals an emission mechanism commonly invoked for flat spectrum radio quasars (FSRQs), that is, inverse Compton scattering on an external soft photon field from the dusty torus, also known as external Compton. The light curve and SED phenomenology was consistent with an interpretation of a blob propagating through a helical structured magnetic field and eventually crossing a standing shock in the jet, a scenario typically applied to FSRQs and low-frequency peaked BL Lac objects (LBL). Also in this work VLBI measurements were important in defining the emission scenario.

1.5 BL Lacertae

BL Lacertae was considered as a prototypical blazar with no emission lines in its optical spectra: actually, it showed characteristics typical of FSRQs in many other occasions [i.e. 13], making it interesting to explore its transitions in a broadband context. BL Lac is a very variable source in several wavelenghts, including VHE gamma-rays and the many MWL campaigns conducted recently can help to shed light on its nature. Recently, several intense flares in the VHE gamma-ray range are under study from the MAGIC collaboration and MWL collaborators, and the soon-to-be-published results will provide a broadband dataset very useful to model this particular source and explore its possible transitions.

2. Current efforts in the study of transitional blazars

Since the first studies on the nature of transitional blazars [14, 15], many MWL campaigns provided important results and identified several sources of controverse categorization or showing apparent transitions from different states. Recently several efforts are pointing to investigate the nature of those transitions and to put them in context with a common evolving emission scenario [16, 17]. VLBI observations, together with MWL lightcurves, can be used to constrain the emission mechanism.

3. Our line of research

Our studies on transitional blazars aim to use two-zones leptonic models taking into account the information provided by VLBI measurements. With the recently published-dataset from OT 081, B2 1420+32, and the soon-to-be-published dataset from OP 313 and BL Lac we will work on a common two-zone model which can take into account the temporal evolution of the sources and explain the observed transitions. A starting point for us is the modeling described in [18].

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