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Multi-messenger characterization of Mrk501 during historically low X-ray and gamma-ray activity

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Blazars, together with other active galactic nuclei, are the most luminous persistent sources in our universe; and therefore a prime candidate for very-high-energy (>0.2 TeV, VHE) gamma-ray observations. For the two MAGIC telescopes, the Mrk501 galaxy is among the brightest observed blazars due to its proximity.

We report a multi-wavelength and multi-messenger study of Mrk501 with data from 2017 to 2020, when Mrk501 showed a VHE flux typically below 10% that of the Crab Nebula. During this time, we performed three long observations with NuSTAR, which characterized the hard X-ray emission during three different low-activity flux levels. This Mrk501 dataset provided the unprecedented opportunity to study multi-wavelength variability and correlations with sensitive instruments during historically low X-ray and VHE gamma-ray emission (below 5% of the Crab Nebula flux in the VHE range), which could be considered as the baseline emission of Mrk501. We complemented the broadband spectral energy distributions (SED) of the identified historically low X-ray and VHE gamma-ray flux with data published by IceCube, in order to evaluate the potential existence of a hadronic component that is stable (or slowly variable), and less visible than the leptonic component that may dominate the emission during typical and flaring activity. In this contribution, we will also describe the evolution of the broadband SED comparing different theoretical scenarios.

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Due to its brightness Mrk501 can be studied in detail during both flaring and quiescent activity. To further improve our understanding of its behavior regular monitoring campaigns are organized each year including instruments ranging from radio to VHE. In this contribution, we present the multi-wavelength results of this monitoring campaign for a period of four years lasting from 2017 to 2020. The data set includes data from MAGIC, *Fermi*-LAT, *NuSTAR* and the *Neil Gehrals Swift* observatory alongside different optical R-band and radio results.

Both in the VHE as well as the X-ray energy range the source showed a historically low activity from mid-2017 to mid-2019. This is quantified by a constant flux hypothesis that is successfully applied to the MAGIC data of the identified low state period. An average flux of around 5% of the Crab Nebula flux above 0.2 TeV (Crab unit) fits the flux state of this period while the typical flux level of Mrk501 is around 30% that of the Crab unit [2]. In addition, the long-term X-ray lightcurve displayed on the XRT monitoring webpage[1] [1] shows extremely low activity during this time interval in comparison to the overall behavior since 2005. Furthermore, three long exposure *NuSTAR* observations were conducted shortly before and during the low-state period.

This extensive data set is very well suited for investigating the multi-wavelength behavior around the low state including both variability and correlation studies alongside spectral studies. For the low state in particular a very detailed spectral evaluation is considered since it could be interpreted as the baseline emission of Mrk501. This baseline emission could be a stable and always present component of the blazar emission that is usually outshone by more variable and brighter components.

A very precise SED can be obtained by combining the monitoring data of this two year low activity data set with the NuSTAR observation conducted on the 20$^{\text{th}}$ of April 2018. We modeled the low-state SED using different physical scenarios such as standard one-zone synchrotron self Compton scenarios [see e.g., 3, 4] applied by using two independent frameworks: a modified naima [6] framework and the public jetset framework[2] [see 7–10]. Additionally, a standard hadronic scenario was investigated using the numerical code described in [11].

Moreover, the earlier two of the *NuSTAR* observations conducted around one and two months before the start of the low activity allow us to combine the multi-wavelength data with two additional comprehensive broadband SEDs. This allows us to investigate the evolution of the source before the low state. All three SEDs as well as earlier published data can be used to test our hypothesis of a stable baseline region with a more active zone dominating the blazar emission.

This first characterization of the low activity of Mrk501 suggests promising results. The baseline emission seems to be explicable both by standard leptonic as well as hadronic scenarios, which are compatible with the expected neutrino flux from ten years of IceCube data [5]. Furthermore, the hypothesis of this baseline emission being a constant component of the blazar emission holds under the first test. More detailed spectral studies together with variability and correlation analysis will be presented to further support the assumptions of this contribution. This could help to disentangle

[1] https://www.swift.psu.edu/monitoring/source.php?source=Mrk501

[2] https://github.com/andreatramacere/jetset/tree/1.2.0rc7, dev branch

the complex behavior of not only Mrk501 but also a broader sample of blazars.

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