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Unveiling the complex correlation patterns in Mrk 421

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The blazar Mrk 421 (redshift $z = 0.031$) is one of the brightest and closest BL Lac type objects, making it an ideal target to probe blazar physics. We report on an extensive multi-wavelength observing campaign in 2017, during which the intra-band correlation patterns show some disparity and complex behaviours. Observations from several instruments are used to achieve an optimal temporal coverage from radio to TeV energies. In particular, four multi-hour *NuSTAR* observations organised simultaneously with MAGIC allow to obtain a precise measurement of the falling segments of the two spectral components. A detailed investigation of the very-high-energy (VHE; > 100 GeV) versus X-ray flux correlation is performed, by binning the data into several sub-energy bands. A positively correlated variability is observed, but the correlation characteristics change substantially across the various bands probed. Furthermore, during the simultaneous MAGIC and *NuSTAR* observations a clear change of the Compton dominance is detected without a simultaneous change in the synchrotron regime, indicating "orphan gamma-ray activity". We also investigate an intriguing bright flare at VHE without a substantial flux increase in the X-rays. Within a leptonic scenario, this behaviour is best explained by the appearance of a second population of highly-energetic electrons spanning a narrow range of energies. Finally, our multi-wavelength correlation study also reveals an anti-correlation between the UV/optical and X-ray bands at a significance level above 3σ.

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Mrk 421 is a high-frequency peaked BL Lac (HBL) type object located at a redshift $z = 0.031$ [1]. Its proximity and flux brightness allow us to achieve a significant signal detection on short time scales (within $\lesssim$ 1 day), from radio to very-high-energy (VHE; $>$ 100 GeV) gamma rays. The temporal evolution of the broadband emission can thus be characterised with a higher degree of precision compared to other BL Lac type objects, making Mrk 421 an ideal target to study blazar jet physics. Between December 2016 and June 2017, we organised an extensive multi-wavelength campaign on Mrk 421. Data from many instruments were collected in order to obtain excellent coverage in energy and time. At very high energies, the observations were carried out by the MAGIC and FACT telescopes. In the high-energy band (0.2-2 GeV & 2-300 GeV), we used measurements from the *Fermi*-LAT instrument. The gamma-ray measurements were complemented by an impressive X-ray coverage using data from the *Neil Gehrels Swift Observatory (Swift)* satellite, as well as four deep exposures from the sensitive hard X-ray satellite *NuSTAR* that took place simultaneously with MAGIC observations. In the UV and optical bands, the observations were made by *Swift*-UVOT and telescopes from the GASP-WEBT network. Finally, OVRO, Medicina and Metsähovi observations were performed to characterise the behaviour in the radio band.

During the first half of the campaign, the source showed several days of high flux activities in the VHE band. The flux above 200 GeV was regularly higher than that of the Crab Nebula, which is more than twice the typical flux of Mrk 421 [2]. In particular, a short and bright VHE flare was detected on 2017 February 4. On that day, FACT measurements revealed a maximum VHE flux of about 7 times that of the Crab Nebula. However, only a moderate flux increase was detected in the X-ray band and the emission at $\approx$ 1 keV remained close to the typical level of Mrk 421. In addition, the flux in the optical/UV and *Fermi*-LAT energy bands did not show any significant enhancement. By studying the evolution of the broadband spectral energy distribution (SED), we find that this behaviour is difficult to reproduce within a standard one-zone synchrotron self-Compton (SSC) model. Instead, the VHE flare could be explained by the emergence of a small emitting zone filled with a narrow distribution of highly energetic electrons. The radiation from this compact emitting blob would combine with that from a larger emitting zone responsible for the quiescent state and dominate the emission only in the hard X-ray and VHE regimes, thus reproducing the observed SEDs.

Using the simultaneous MAGIC, *NuSTAR* and *Swift*-XRT data, we investigate the VHE versus X-ray correlation throughout the campaign by binning the data into several sub-energy bands. A positively correlated variability is observed, as already reported for Mrk 421 [3]. However, the characteristics depend substantially on the energy bands probed. The correlation ranges from a sub-linear to a more-than-cubic relation. Furthermore, we report significant variability in the Compton dominance by a factor $\approx$ 3 during the *NuSTAR* observations, without any simultaneous change of the synchrotron emission. Based on an SSC model, we show that this "orphan gamma-ray activity" may be explained by an emitting zone that is adiabatically expanding over time, without a significant loss in the total number of electrons.

The temporal evolution of the synchrotron emission is also characterised in detail by exploiting the dense temporal coverage in the optical, UV and X-rays. The location of the synchrotron peak frequency shifted by about two orders of magnitude throughout the campaign, from $\sim 10^{16}$ Hz to $\gtrsim 10^{18}$ Hz. Furthermore, the UV/optical and X-ray fluxes exhibit anti-correlated variability at a significance level above 3σ. Mrk 421 is the only BL Lac where such a behaviour was observed so

far and it indicates variations in the efficiency of the particle cooling and acceleration mechanisms.

Detailed information about analysis and results have been published in [4].

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References

[1] de Vaucouleurs G., de Vaucouleurs A., Corwin H. G., Buta R. J., Paturel G., Fouque P., 1991, rc3..book

[2] Acciari V. A., Arlen T., Aune T., Benbow W., Bird R., Bouvier A., Bradbury S. M., et al., 2014, APh, 54, 1.

[3] Aleksić J., Ansoldi S., Antonelli L. A., Antoranz P., Babic A., Bangale P., Barres de Almeida U., et al., 2015, A&A, 576, A126.

[4] MAGIC Collaboration, Acciari V. A., Ansoldi S., Antonelli L. A., Arbet Engels A., Artero M., Asano K., et al., 2021, arXiv, arXiv:2106.05516

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