Unveiling the complex correlation patterns in Mrk 421

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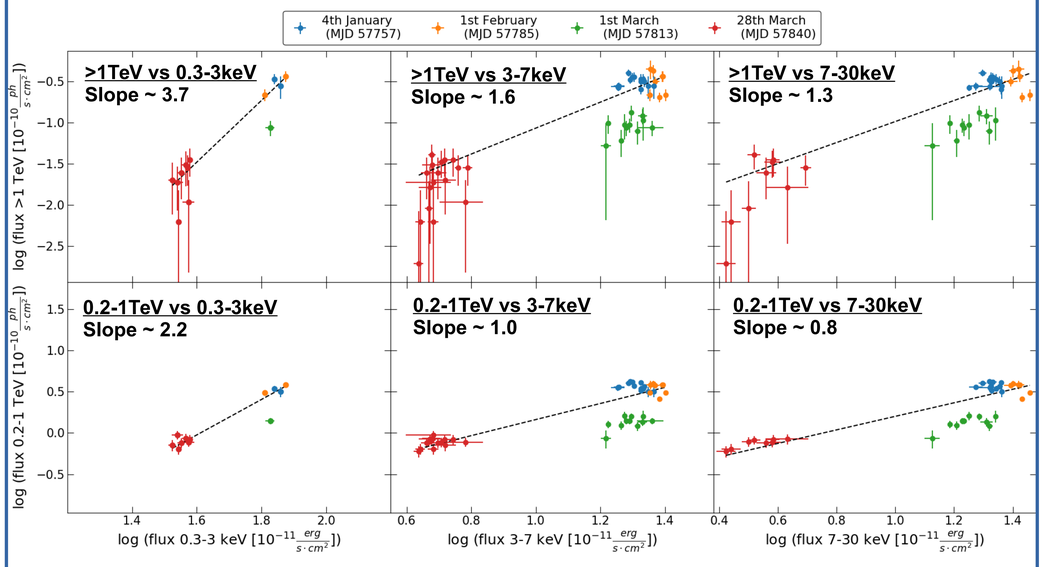
1 Introduction

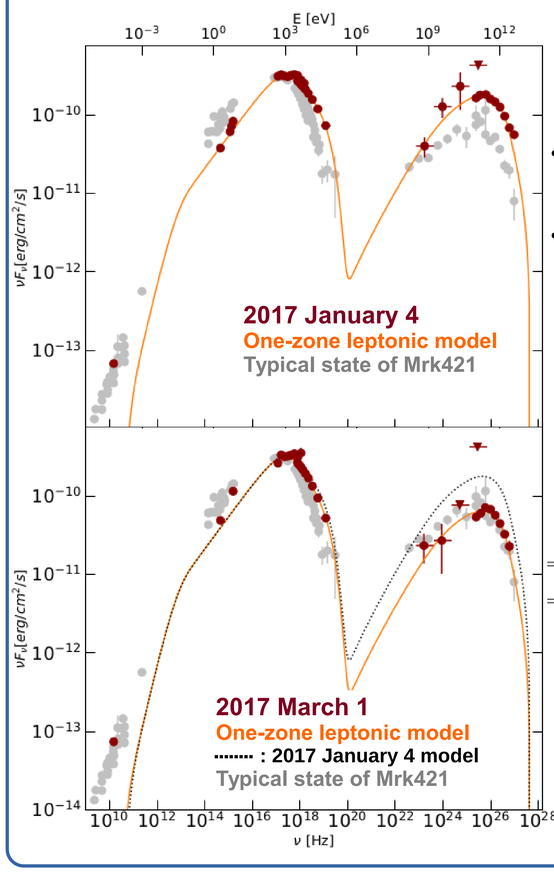
We report on an extensive multiwavelength study of the TeV blazar Mrk 421 (redshift z=0.031 [1]) using data taken between 2016 December and 2017 June. The observing campaign involved the MAGIC, FACT, *Fermi*-LAT, *Neil Gehrels Swift Observatory (Swift)*, GASP-WEBT, OVRO, Medicina and Metsähovi telescopes. This study also includes four multi-hour long exposures with simultaneous MAGIC, *NuSTAR* and *Swift* observations, providing a precise measurement of the falling segments of the two spectral bumps. Based on this dataset, we characterise the intra-band correlation patterns in Mrk 421. The observations are compared with theoretical models.

2 Very-high-energy vs X-ray flux correlation



- Very-high-energy (VHE; E>100 GeV) versus X-ray flux correlation characterised in different sub-energy bands.
- Tight correlation in each energy combination (Pearson's coefficient >0.8), in agreement with leptonic scenarios.
- Correlation characteristic varies substantially across spectral bands.
- Linear fits in log-log plane: slope ranges from ~3.7 (>1 TeV vs 0.3-3 keV; dashed black line) to ~0.8 (0.2-1 TeV vs 7-30 keV). In each X-ray band (along X-axis), correlation slope increases when going from 0.2-1 TeV (bottom panels) to >1 TeV fluxes (top pannels).
- Data on **2017 January 4** and **2017 February 1** have ~3 times higher VHE flux compared to **2017 March 1** despite very similar X-ray states.
  → "orphan" gamma-ray activity (see Sect. 3).

3 "Orphan" gamma-ray activity



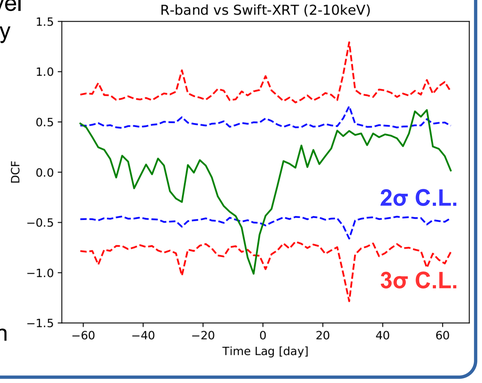
- On 2017 January 4: gamma-ray spectral energy distribution (SED) factor ~3 brighter than 2017 March 1 despite same X-ray states.
- One-zone leptonic model describes data well.
- Change of gamma-ray flux due to adiabatic expansion of emitting zone over time without significant loss of electrons.
  → SEDs described with same magnetic field strength and electron spectral distribution, but radius of emitting blob about twice larger on 2017 March 1 compared to 2017 January 4.

Parameters	MJD 57757 4th January 2017	MJD 57813 1st March 2017
Γ_b	25	25
B' [10^{-2} G]	6.1	6.1
R' [10^{16} cm]	1	1.65
U'_e [10^{-2} erg cm^{-3}]	1.1	0.24
α_1	2.2	2.2
α_2	3.8	3.9
γ'_{min} [10^3]	1.0	1.0
γ'_{br} [10^5]	2.1	2.1
γ'_{max} [10^6]	1.5	1.5

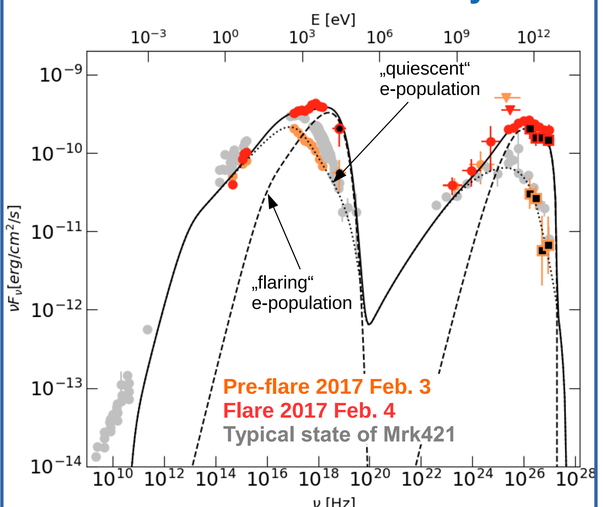
Note. Γ_b: bulk Lorentz factor of emitting zone set equal to Doppler factor, B': magnetic field, R': radius of emitting zone, U'_e: electron energy density, α_1, α_2: power-law indices below and above the break of the electron distribution. $\gamma'_{min}, \gamma'_{br}, \gamma'_{max}$: minimum, break and maximum Lorentz factor of electron distribution.

4 Optical vs X-ray *anti*-correlation

- Anti-correlation at a significance level above 3σ between optical and X-ray fluxes at ~0 time lag.
- Confidence level (C.L.) estimated via Monte-Carlo simulations.
- Reported only once so far with a low significance [2].
- Suggests shift of synchrotron emission component due to changes in cooling and acceleration efficiency of electrons.



5 VHE Flare on 2017 February 4



- Strong VHE flare on 2017 February 4:
  → ~4 times the Crab Nebula flux above 200 GeV
- No flare in optical/UV and MeV-GeV bands. Flux at ~1 keV at the level of Mrk 421 quiescent state.
- One-zone leptonic model disfavoured
  → Two-zone leptonic model more natural scenario.
- VHE flare caused by appearance of 2nd emitting zone ("flaring" zone; black dashed line in figure above) adding up to a quiescent emitting zone (black dotted line in figure above).
- "flaring" zone filled with narrow distribution of freshly accelerated electrons, dominating emission in hard X-rays and VHE bands. Quiescent zone responsible for pre-flare state on 2017 February 3 (orange data points).

References/Acknowledgments

[1] de Vaucouleurs, G. et al. 1991, Springer-Verlag Vol. 1-3, XII, 2069, 7
[2] Aleksić J. et al., 2015, A&A, 576, A126

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The FACT acknowledge the support from the agencies and organizations listed here: https://fact-project.org/collaboration/icrc2021_acknowledgements.html