Looking for a repeating flaring pattern in Markarian 421, from X-ray to gamma ray

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Introduction

Markarian 421 is the brightest high frequency peaked BL Lac (HBL) observed in X-rays and gamma rays. Its radio jet, observed at a resolution below milliarcsecond with the VLBA, shows four stationary components. Interpreting these components as four stationary shocks (see Fig. 1), a distinct variability pattern is expected to be observed each time a strong perturbation propagates through the jet.

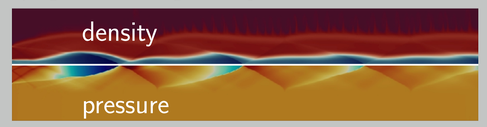

Figure *1: Example of a relativistic jet simulation displaying stationary recollimation shocks [1].*

How to probe fast underlying flows in HBLs?

A perturbation in the flow, such as a propagating shock or overdensity, is expected to trigger a flare when crossing a stationary knot. For a given apparent speed β_{app}) , the time delay of the secondary flares can be set knowing the radio knot positions. Considering a constant speed of the flow through a straight jet, the time gap Δt between each successive flare in the lightcurve should be directly proportional to the observed inter-knot gap Δx. We have the relation $\Delta t_i = (1+z)\Delta x_i/(c\beta_{app})$.

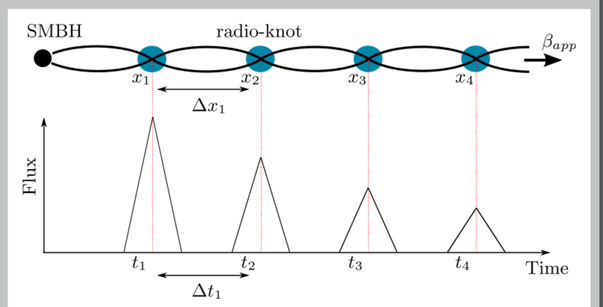

Figure *2: Simplified scheme of the expected lightcurve signature of a perturbation crossing the knots x_i with an apparent speed β_{app} linking the inter-knot distance Δx_1 with the delay between two consecutive flares Δt_1.*

X-ray results from a 2019 study

A regular flaring pattern associated to the radio knots in the Mrk 421 jet was identified by [2]. The scenario of a main flaring zone in the most upstream radio knot was favored at a significance level above 3σ against stochastic fluctuations. Such a pattern is consistent with a flow apparent speed of 45 ± 4c.

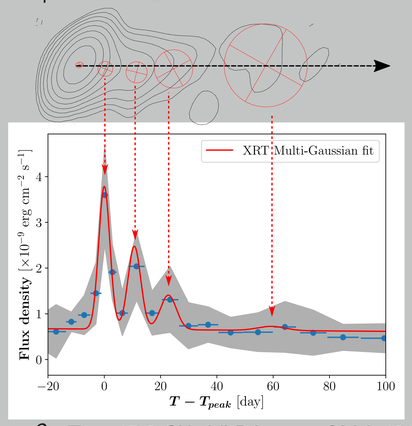

Figure *3: Top: 15.3 GHz VLBA map of Mrk 421 taken Jan. 14th 2011 showing 4 radio knots downstream the core (adapted from [3]). Bottom: Lightcurve resulting of stacked flares fitted by a parametrized multi-Gaussian function [2].*

New radio VLBA observations

In 2020 we launched an observation campaign at 15.3 GHz with the VLBA to check the positions of the knots. We can see below the two outermost knots slowly moving away from the core, with a maximum apparent speed of 0.14 c.

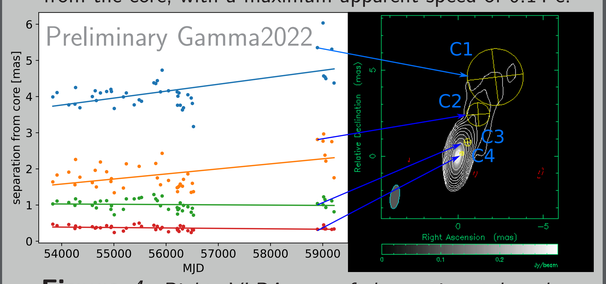

Figure *4: Right: VLBA map of observations taken the Feb 19, 2022. Left: Evolution of the radio knots distances to the core. Data from 2006 to 2014 comes from the MOJAVE program [4].*

Building mutiwavelength 1-day binned lightcurves

In order to check for the existence of a flaring pattern in Mrk 421 with high statistics, we are building decade-long, 1-day binned lightcurves over multiple energy bands. Below are the lightcurves in X-ray (Swift-XRT, MAXI), gamma-ray (Fermi-LAT), and very-high energy (VERITAS, FACT). We aim to finalize this dataset integrating the full lifetime of Fermi-LAT and adding the few last years of VERITAS operation.

Discussion and next steps

This poster show the milestone achieved in our efforts to check if a flaring pattern does exist with high statistical significance in the decade-long multiwavelength dataset of Mrk 421. Such a discovery would deeply change our understanding of high-energy emission processes in AGN. Thanks to a successful VLBA campaign in 2020, we now have a precise view of the long-term evolution of Mrk 421 radio knots. With currently 7801 individual flux points analyzed (and increasing), we have gathered one of the largest high-energy dataset ever build for a blazar. This is the fruit of intense long-term monitoring programs on Mrk 421 achieved by VERITAS, Swift-XRT, and FACT.
After completing our dataset we will probe the existence of a multiwavelength flaring pattern. Stay tuned!

Acknowledgments

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References

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