Simultaneous X-ray and gamma-ray observations of Mrk 421 during a flaring episode in 2014

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Introduction

• Blazars are active galactic nuclei (AGNs) with a relativistic jet pointing at the observer.
  • They are extremely luminous, energetic, and variable on timescales months down to minutes.
  • Particles (electrons and/or protons) are accelerated to relativistic speed in turbulent magnetic field in jets, producing non-thermal radiation.
  • Blazar radiation exhibits two-peak spectral energy distributions (SEDs), with an electron synchrotron peak in IR ~ X-ray, and a γ-ray peak which may be of either leptonic or hadronic origin (e.g. [1]).

• Correlated multiwavelength (MWL) variabilities are important for studying the particles and magnetic field in the jets, and their spatial structure (e.g. [2],[3]). Simultaneous MWL observations during flares are needed but rare, especially those focusing on variability on sub-hour timescales, which may be different from variability on longer timescales [4].

• The Very Energetic Radiation Imaging Telescope Array System (VERITAS) is an array of four 12-meter imaging atmospheric Cherenkov telescopes in southern Arizona, featuring:
  • sensitivity to very high energy (VHE) radiation at ~100 GeV ~30 TeV, field of view (FoV) 3.5°;
  • angular resolution ~0.1°, energy resolution ~15%;
  • 5 σ detection of a point source of 1% Crab Units (C.U.) in ~25 hours [5].

• The XMM-Newton satellite carries the European Photon Imaging Camera (EPIC) X-ray CCD camera and the Optical/UV Monitor (OM), featuring:
  • X-ray coverage between ~0.5 ~30 keV, FoV of 30°;
  • UV/optical coverage 170 - 650nm, FoV of 17°;
  • unique long orbital period of ~48 hr providing gapless coverage.

Results: temporal variability

• Figure 1 shows simultaneous light curves in VHE, X-ray, and UV bands.
  • The VERITAS light curves: binned in 10-minute intervals, flux integrated from the energy threshold of 315 GeV for the first ~3.5 hr and 560 GeV for all data on April 29, and 225 GeV on May 3.
  • The XMM EPN light curves: count rate between 0.5 to 10 keV binned in 50-s intervals.
  • The XMM OM light curves: count rate with UVW2 filter (200-300 nm) in both image and fast mode. Fast mode count rates are binned in 50-s intervals and plotted in black, and image mode count rates are binned by exposure and plotted in red.

• Figure 2: ZDCF between 0.5-1keV, 1-3keV and 3-10keV on April 29 (left) and May 3 (right), respectively. Positive lag values indicate “hard lag”.

• Cross-band correlations probe particle acceleration timescales and cooling timescales (e.g. [7]).
  • Z-transformed discrete correlation functions (ZDCF) [8] are calculated between soft and hard X-ray light curves, as shown in Figure 2. ZDCFs on Apr 29 show evidence of possibly hard X-rays lagging soft X-ray emission (“hard lag”), but on May 3 the opposite “soft lag” scenario are more likely. The more commonly observed “soft lag” indicates a harder spectrum when flux rises and a softer spectrum when flux falls, corresponding to a clockwise loop in spectral hysteresis plots (e.g. Figure 4).

Results: spectral variability

• The SED of simultaneous VERITAS and XMM-Newton data and contemporaneous MWL data are shown in Figure 3. Daily averaged high energy (HE) gamma-ray spectra were constructed from Fermi-LAT data between 100 MeV and 300 GeV. Optical spectra from Steward Observatory between 400 and 750 nm on May 3, radio data from CARMA at 93 GHz taken on the both nights, and from OVRO at 15 GHz on other nights within the week are also shown.

• Spectral hysteresis has been observed from blazars, mostly from HBLs in X-ray band (e.g. [9]), as well as from a few PSBs in HE gamma-ray band (e.g. [10]). Figure 4 shows possible spectral hysteresis in both X-ray and VHE during the ToO observations, the latter of which has not been observed before. The X-ray spectral hysteresis loop goes counter-clockwise on Apr 29 and clockwise on May 3, consistent with the “hard/soft lag” results.

Observations of flaring blazar Mrk 421

• Mrk 421 is a nearby BL Lac object (z=0.031) and one of the brightest and most variable AGNs in VHE. On 2014 Apr 25, an elevated flux from Mrk 421 according to a MAGIC automatic online analysis triggered a joint target of opportunity (ToO) program by XMM-Newton, VERITAS and MAGIC. With the help of the long orbital period of XMM-Newton, three ~4-hour-long gapless and simultaneous X-ray and TeV gamma-ray observations were carried out on Apr 29, May 1 and May 3.

• Due to dusty weather at VERITAS site on May 1, only data from Apr 29 and May 3 are used. The VERITAS observations on these two nights were taken in “wobble” mode [6] with 0.5° offset, with zenith angle between 10 to 40 deg, yielding a total live exposure time of 6.14 hr. XMM observations were taken in EPN timing mode and OM image fast mode.

References / acknowledgement

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References / acknowledgement


Figure 1: XMM and VERITAS light curves of Mrk 421 from two simultaneous ToO observations on 2014 Apr 29 (upper) and May 3 (lower).

Figure 2: ZDCFs between 0.5-1keV, 1-3keV and 3-10keV on Apr 29 (left) and May 3 (right), respectively. Positive lag values indicate “hard lag”.

Figure 3: SED of Mrk 421 consisting of simultaneous VHE, X-ray, and UV data, as well as contemporaneous MWL data on Apr 29 (cyan) and May 3 (blue).

Figure 4: Spectral hysteresis in VHE and X-ray on Apr 29 (upper) and May 3 (lower). The variability of spectral index and flux (or rate) are shown on the left. The spectral index vs. flux (or rate) are shown on the right.