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Multi-wavelength monitoring of the highly active blazar Mrk 421. Investigating high vs. low energy correlated variability

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Abstract: We present a long-term multi-wavelength monitoring of blazar Mrk 421, obtained simultaneously with orbital and ground-based instruments. Daily optical observations from the University of Athens Observatory started as a follow-up monitoring of the major gamma-ray flare of 12 April, 2013. This data set is compared with the gamma-ray, X-ray and UV observations obtained with Fermi/LAT and SWIFT satellite telescopes respectively, as well as with the 95 GHz and 15 GHz data from the CARMA and OVRO 40-m radio telescope.We investigate the existence of correlated variations among the different wavebands using the discrete correlation function (DCF) technique.

1 Introduction

Mrk 421 is one of the closest blazars to Earth (z=0.03) exhibiting large amplitude, rapid variations across the electromagnetic spectrum. It is extensively monitored in various wavelengths (e.g. [3], [5], [1]). Temporal correlations between two energy bands have been detected in the past (e.g., [4]; [3], [6]). This behavior along with the fact that most campaigns with wide spectral coverage have shorter temporal coverage has motivated our long-term optical monitoring of Mrk 421.

2 Multi-wavelength sample

Our sample consists of contemporary data in seven different energy bands: gamma-rays (FERMI/LAT), hard X-rays (Swift/BAT), soft X-rays (Swift/XRT), UV (Swift/UVOT), optical (UoA), millimeter (CARMA) and radio (OVRO) wavelengths (Fig.1). The data sets extend over the period of about 600 days (MJD 56300-56900). The optical observations (R-band) were performed from the University of Athens Observatory in a daily basis. It is one of the most comprehensive optical observing campaigns, in terms of duration (temporal coverage), density of data (most observations were obtained on a daily basis) and homogeneity (data have been obtained with a single instrument). The CARMA 95 GHz data were obtained as part of the Monitoring of gamma-ray Active galactic nuclei with Radio, Millimeter and Optical Telescopes (MARMOT) program (http://www.astro.caltech.edu/marmot/), while the OVRO 40-m 15 GHz data were obtained as part of an on-going blazar monitoring program where approximately 1800 blazars are observed with twice per week cadence [7].

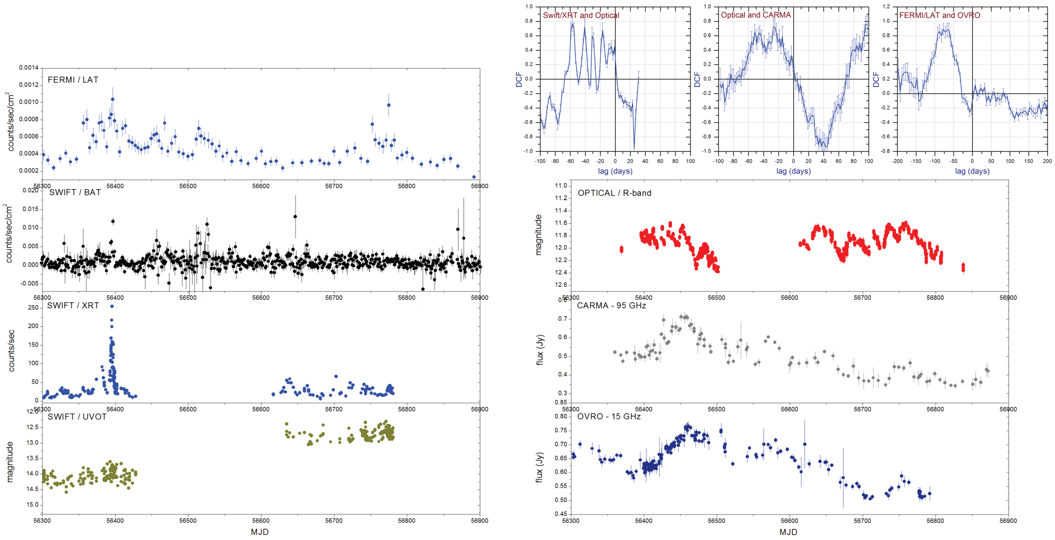

Figure 1: Our MW sample consists of contemporary data in seven different energy bands and extends over a period of 600 days. The three top-right panels show DCF plots, calculated from these datasets.

3 Results extracted from DCF analysis

We estimate the Discrete Correlation Function (DCF) using the method described by [2]. Setting the peak time of the gamma-ray flare (MJD 56394) as zero time we detect corresponding flares in lower energies (optical, millimeter and radio) a few days later. Subtracting the brightness peak time of each data set from the gamma-ray flare time we get: 0 day lag between FERMI/LAT and Swift/BAT (MJD 56394±1), 1 day lag between Swift/BAT and Swift/XRT (MJD 56395±1), 41-58 day lag between Swift/XRT and Optical (MJD 56435±2), 25 day lag between Optical and CARMA (MJD 56460±2), and 2 day lag between CARMA and OVRO (MJD 56461±2). As a consequence we see ∼65-90 day lag between FERMI/LAT and OVRO. Overall, we find a time lag between high and low energies of the order of ∼65-90 days. A similar correlation was found by [6] when radio, millimeter and gamma-ray data sets of slightly longer duration were cross-correlated and it was found that a gamma-ray flare was followed by a radio flare at 15 GHz after ∼40-70 days.

The R-band light curve shows a multi-peak behavior, which, in turn, gives several peaks in the corresponding DCF plot. Such features are not visible in the DCF plots between other data sets due to the less dense sampling in other energy bands. In addition, we detect several short duration flares in the optical light curve. Their appearance frequency is ∼20-40 days. The flares rise timescale is ∼5-10 days, while their decay time is longer (∼20-25 days). Preliminary calculations give a 1/e folding time of approximately 30 days and they show that all flares share the same decay rate (see similar results in [6]). These flares cannot be detected when sampling is relatively sparse (sampling every 3 days).

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