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Simultaneous Multi-wavelength Variability of the TeV Blazar Mrk 421

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We report results of simultaneous monitoring of the TeV blazar Mrk 421 in radio to TeV energy bands. The observations were aimed at studying the correlation in multi-wavelength variability. The observing runs for this study (25 February - 5 March 2003) were conducted using the RXTE and several ground based telescopes. Flaring activity have been observed on several occasions in different wavelengths. Present observations show, the source was in active phase at lower energies during the campaign. Variability in different wavelengths are found to be correlated. These results presented here are explained by the possible emission mechanism models.

1. Introduction

A small subgroup of radio-loud active galactic nuclei (AGNs) known as blazars, show significant flux variability in the complete electromagnetic (EM) spectrum, variable polarization and their radiation at all wavelengths is predominantly non-thermal. Blazar is a collective name of three subclasses (BL Lac objects, optically violent variables OVVs and high polarization quasars HPQs) of radio-loud AGNs. In a unified model of radio-loud AGNs based on the angle between the line of sight and the emitted jet from the source, blazars make angle of $< 10°$ [1]. Since, blazars emit radiation in the complete EM spectrum which gives an excellent opportunity to study the spectral energy distribution (SEDs) along the complete EM spectrum. It is found from the studies, blazars SEDs have two peaks. The first component peaks anywhere from IR to X-ray. Those peaking anywhere from IR to optical are called low energy blazars (LBLs) and at UV/X-ray are called high energy blazars (HBLs). The electromagnetic emission is dominated by synchrotron component at low-energy and at high-energy by inverse Compton component [2-4].

Mrk 421 is the nearest detected TeV BL Lac object (z = 0.031) and classified as a HBL. It was first noted to be an object with blue excess which later turned out to be an elliptical galaxy with bright point like nucleus [5]. Mrk 421 was the first extragalactic object discovered at TeV energies [6,7]. It is one of the TeV blazar detected by COMPTEL and EGRET instruments aboard the CGRO [8,9]. It is also detected by STACEE [10].

Mrk 421 variability has been studied in all EM regimes in isolation. In an exhaustive compilation of radio data at 22 and 37 GHz results for about 25 years for several extragalactic sources including Mrk 421 were reported by [11,12]. NIR results for three decades data of several blazars including Mrk 421 were given by [13]. A much systematic and comprehensive study for the source was done by [14] in the same period of the campaign for which the present paper is written. In the compiled optical data for long term observations, variation of 4.6 mag was reported by [15] and rapid variability of 1.4 mag in 2.5 hours was reported by [16]. There are several simultaneous X-ray and gamma-ray as well as multi-wavelength campaigns for the source [17-21].

In the present paper, we aimed to search for correlated multi-wavelength variability in Mrk 421. This kind of study will be an important tool for understanding the emission mechanism of blazars. The most telling result about the emission mechanism will almost certainly emerge from multi-wavelength observations that simultaneously monitor a particular object for an extended period. Here we report one of the best sampled observations for correlated variability in synchrotron and inverse Compton scattered components. Almost in the complete campaign, the source has shown similar variability pattern in the NIR and X-ray bands.

Section 2 presents the details about observations, data reduction and the data taken from the published literature. In section 3 results of the present work and in section 4 our conclusions are given.

2. Observations, Data and the Data Reduction

2.1 TeV Observations with PACT

Pachmarhi Array of Čerenkov Telescopes (PACT), based on wavefront sampling technique, is being used for detection of TeV gamma rays from astronomical sources. Details of this array are given in [25]. Observations of Mrk 421 were carried out with PACT during 26th February to 5th March, 2003 in ON-OFF mode. During these nights 2 sectors out of 4 were aligned along the source direction and remaining 2 were looking at the background region simultaneously. A number of preliminary checks were carried out on the data before doing actual analysis. It was found that data taken on 26th and 27th Feb, 3rd and 5th Mar were very bad therefore rejected. Observations taken on 28th Feb, 1st, 2nd and 4th Mar are analyzed. Details of analysis procedure are given in [25]. During these nights no excess of events over the background is detected, implying γ-ray flux is close to or below the sensitivity limit of PACT.

2.2 X-Ray Observations with RXTE

We have analyzed Mrk 421 data observed with RXTE during 26/2/2003 - 6/3/2003. We have extracted archival data sets corresponding to this multi-wavelength campaign under the guest observing program 80172. RXTE has two types of detectors viz, Proportional Counter Array (PCA) and High-Energy X-ray Timing Explorer (HEXTE) on-board along with All Sky Monitor (ASM). The PCA consists of five identical xenon filled proportional counter units (PCUs) covering an energy range of 2-60 keV. During these observations only PCU 0 and PCU 2 were used. Since PCU 0 lost pressure in the top veto at the beginning of Epoch 5, we have used only data from PCU 2. HEXTE consists of two clusters of phoswich scintillation detectors covering an energy range of 15-250 keV, but is less sensitive. We do not discuss HEXTE data here. ASM consists of three xenon filled position sensitive proportional counters with field of view of 6×90 degrees. It covers 80% of the sky every 90 minutes and spans an energy range of 2-10 keV.

We analyzed Standard 2 PCA data which has a time resolution of 16s with energy information in 128 channels. Data reduction is done with FTOOLS (version 5.3.1) distributed as part of HEASOFT (version 5.3). For each of the observations, data was filtered using standard procedure for faint sources given in RXTE Cook Book. For extraction of background, model appropriate for faint sources (pca_bkgd_cmfaintl7_eMv20031123.mdl) was used. Light curves were extracted from data for three energy bands: 2-9, 9-20 and 20-40 keV. Background light curves were also extracted and subtracted from source light curves. We obtained ASM data from MIT archive. Light curves were generated taking one-day average.

2.3 Data from Literature: Near Infrared and Radio Data

Near Infrared data in J band used in the present paper is taken from [14]. They have done observations from 1.2 meter optical/NIR telescope at Gurushikhar observatory, Mount Abu, India using NICMOS-3 detector and J band filter. The detail about NIR observations and data reductions is given in [14].

The radio data in the figure 1 is taken from the recent paper by [12]. They observed the source during the campaign by their 17.7 meter Metsähovi radio telescope at 22 and 37 GHz. The detail about radio data is given in [22].

3. Results

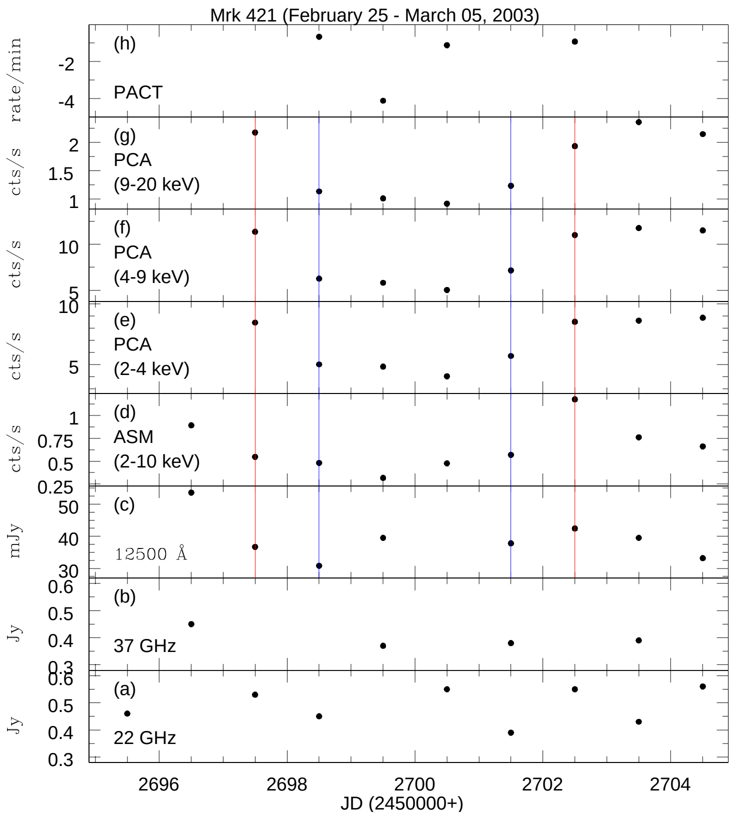

Figure 1. Multi-wavelength data of Mrk 421 as a function of time for all bands from radio to gamma-rays observed during February 25 – March 05, 2003. Vertical lines in panel (c)–(g) show simultaneous variability in NIR and X-ray bands. In general uncertainties are smaller than the symbols, the error bars have been omitted.

Figure 1 gives the radio to gamma-ray light curves for the multi-wavelength campaign during February 25 - March 05, 2003. The data plotted here for different bands of the EM spectrum is daily average. Daily average of a specific date is reported at 00h 00m 00s UT. The radio flux seems to be in stable state, implies variability timescale may be longer than the duration of the campaign. On the other hand gamma-ray data is noisy. The figure shows highly correlated variability among the different energy bands of the PCA data.

The visual inspection of the data for the multi-wavelength campaign in the figure 1 show, a strong correlation in NIR and X-ray bands at JD 2452697.5, 2452698.5, 2452701.5 and 2452702.5. In particular, the source has tendency to come at faint stage at JD 2452697.5 and a flaring activity at JD 2452701.5. NIR and ASM data has shown the correlated variability behavior in the complete campaign except for the JD 2452699.5. At JD 2452699.5, NIR has shown anti-correlation with ASM and PCA data. On the other hand there is anti-correlation in the variability behavior of NIR and PCA data at JD 2452703.5. to 2452704.5. The time lag if present, will be certainly less than a day since the data is binned on one day time scale. The time lag less than a day is referred as more or less simultaneous for another blazar 3C 273 [23]. X-ray and NIR correlation was reported for the first time in another blazar 3C273 by [24].

4. Discussion and Conclusions

We have reported, strongly correlated NIR and X-ray variability in the blazar Mrk 421 from the data collected from a multi-wavelength campaign of the source during February 25 - March 05, 2003. During the campaign source was in very active state in NIR and X-ray bands. Data in radio and gamma-ray bands were inconclusive.

After getting the spectral energy distribution (SED) for the campaign, we expect one-zone synchrotron self-Compton (SSC) model will be able to explain the variability behavior of Mrk 421 during the campaign. From other X-ray and NIR correlated variability in blazar, it has been noticed that external Compton (EC) model does not explain the variability successfully [24]. Further simultaneous observations of the source in X-ray/IR with time resolution of few hours will be useful to determine the time lag and to see whether it is different for different flaring activity.

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