Periodicity in the TeV gamma rays and X rays from Markarian 501

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Abstract

Historical TeV gamma-ray flares from Markarian 501 was observed using Utah Seven Telescope Array (7TA) from the end of March to the end of July of 1997. The Rossi X-ray Timing Explorer All Sky Monitor (RXTE ASM) has been observing X rays from Mrk 501 since Jan. 5, 1996.

We find evidence for periodicities of $23.9^{+2.3}_{-2.0}$ days and $23.9^{+1.6}_{-2.9}$ days from TeV gamma-ray and X-ray light curves using 7TA and RXTE ASM. Their false-alarm probabilities are 8.2×10^{-3} and 5.6×10^{-5}, respectively.

1 Introduction:

BL Lacertae object are considered to be a kind of Active Galactic Nuclei (AGNs) having jet oriented to our line of the sight. Markarian 501 (Mrk 501) is the second closest known BL Lac with red shift z = 0.034.

The big flares of Mrk 501 were detected in 1997 and varied from 0.3 up to several times the flux from the Crab Nebula. These flares were observed by the Whipple (Quinn et al. 1996), HEGRA

(Bradbury et al. 1997), CAT (Barrau et al. 1997), TACTIC (Bhat 1997) and the Utah Seven Telescope Array (Hayashida et al. 1998). The CGRO EGRET has detected gamma rays (E > 100 MeV) from Mrk 501 at a significance level of 3.5σ (Kataoka et al. 1998). According to the All Sky Monitor (ASM) on board the *Rossi X-Ray Timing Explorer* (RXTE) (Remillard and Levie, 1997), the high X-ray activity of the source started in March 1997 and continued on October 1997. It is found that the variation of the intensities are larger in TeV range than X-rays and other ranges (Catanese et al. 1997, Kataoka et al. 1998, Ghisellini 1997). Pseudo periodicity of the TeV gamma-rays in this period was reported by 7TA (Hayashida et al. 1998) and possible suggestion of the correlation between the TeV gamma-rays and X rays for the periodicity was reported by HEGRA (Aharonian et al. 1998, Aharonian et al. 1999).

In this paper, we report a clear evidence of periodicities from independent experiments which observed emissions of photons in TeV and keV region for flares from Mrk 501. In spite of the observations in quite different energy ranges, it shows almost similar period of 23.9 days.

2 Analysis:

We have used datasets for analysis reported by the Utah Seven Telescope Array group for TeV gamma rays during the 1997 flares and the RXTE ASM for X rays from MJD 50087 (Jan. 5, 1996) to 51200 (Jan. 22, 1999) for the present analysis.

Total observation time was 105.4 hours in 47 nights during the 1997 flares. For 7TA, we have selected data obtained under good weather condition which are evaluation by cosmic ray event rate. Eleven observation nights out of 47 nights are omitted in this process.

The RXTE ASM has been regularly observing bright X-ray sources since Jan. 5, 1996. The data is publicly available over the Internet. Dataset for RXTE ASM are selected from light curve data of SSC 1 and SSC 2.

The periodicities of the light curves were examined by the Lomb method (Lomb 1976, Press et al. 1992) because this method can be applied to unevenly sampled data such as observations using the air Cherenkov detector. We can estimate the false-alarm probability from the null hypothesis by the obtained power. A small value for the false-alarm probability indicates a highly significant periodic signal exists. The errors of the period is obtained based on a simple Monte Carlo method by generating millions of datasets with the error of the intensities

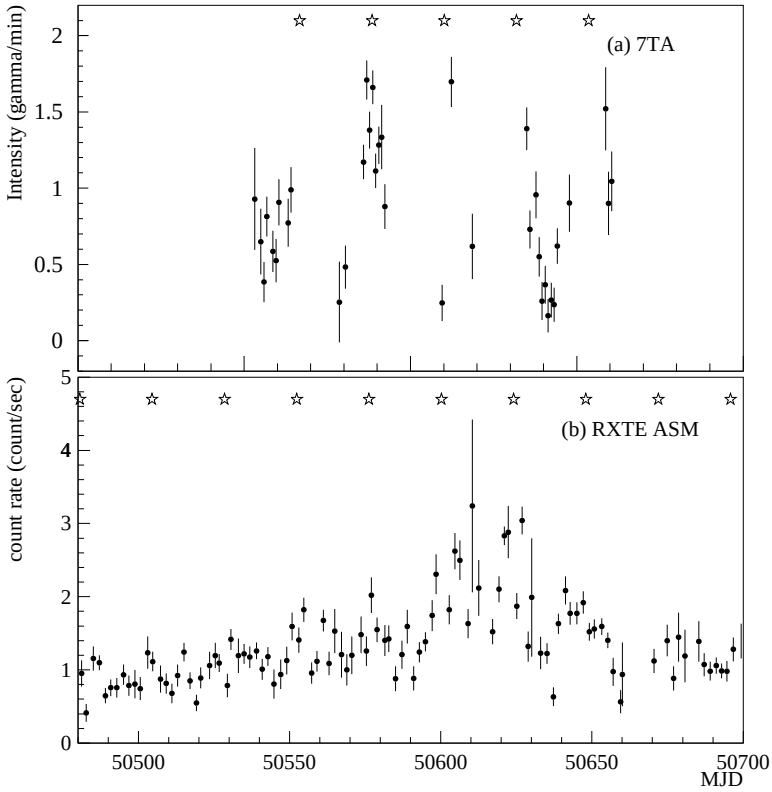

Figure 1: The time variation of the TeV gamma-ray and X-ray intensity from Mrk 501 during 1997 flare (MJD 50480–50700). Data points of the RXTE ASM light curve shows average values over 2 day for clarity while finer datasets are used for the periodicity analysis. Upper stars are placed at the MJD with the maximum intensity of count rate of the fitted sine function for the obtained period.

Table 1: Obtained periods and probabilities for the observation data of TeV gamma-ray and X-ray emissions. Error of the period indicate the period change over which the power drops by a factor of two from the peak.

Experiment	Term [MJD]	Period [days]	Chance probability
7TA	50538 – 50656	$23.9^{+2.3}_{-2.0}$	8.2×10^{-3}
RXTE ASM	50480 – 50700	$23.9^{+1.6}_{-2.9}$	5.6×10^{-5}

having Gaussian distribution.

3 Results:

The power spectra obtained for respective experiments are shown in Figure 2. We have generated 10^6 datasets for 7TA and 10^3 datasets for RXTE ASM. The maximum peak position of the power spectra are 23.9 days (7TA) and 23.9 days (RXTE ASM). The other peak at 13.2 days for 7TA corresponds to about a half of the main period of 23.9 days.
Usually, Cherenkov observations are carried out in the moon-less clear night. Derivation of the probability could be affected by clumping in the data sample (Horne and Baliunas 1986). We have generated dataset which has the same gaps in the observation time by shuffling the observation date (in other words, randomized the observation order of nights). Then these dataset were analyzed in the same way as the real dataset, however, we could not see any effect by the data clumping. The chance probabilities are shown in Table 1.

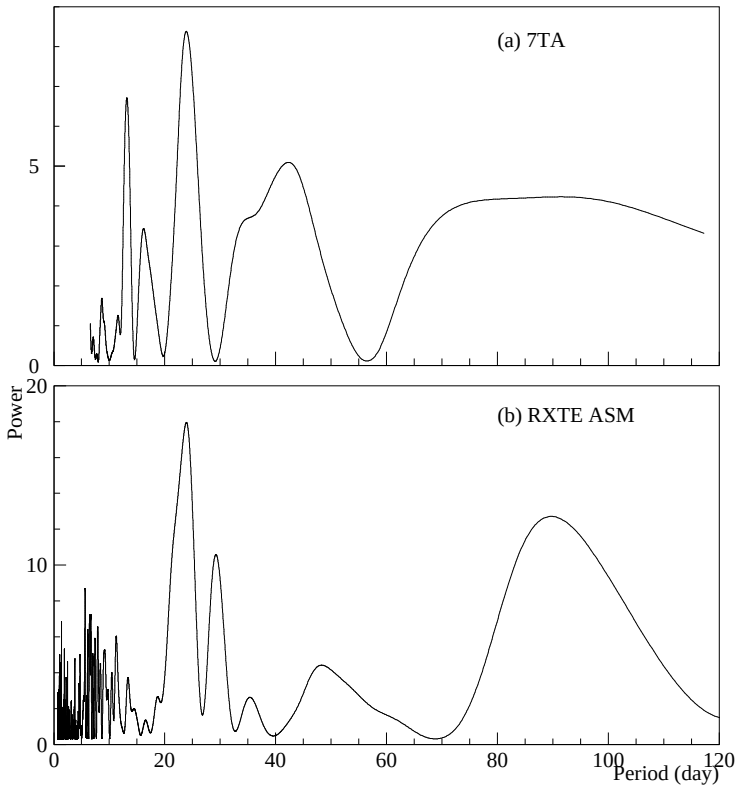

Figure 2: The power spectra derived from the TeV gamma-ray and X-ray light curves for Mrk 501. The highest peaks are seen at the period of 24 days for respective experiments.

4 Discussion:

The power spectrum that we have computed for RXTE ASM dataset has a clear peak at 23.9 days and the phase of light curve is consistent with the result of TeV gamma-rays observation. The consistent periodicities are obtained in two independent experiments. Also the periodicity correlation between the TeV gamma-rays and X-rays was suggested.

This periodicity may suggest that the high energy phenomena around massive black hole(s) could be influenced by factors such as the rotation of the jet and the rotation of the black hole(s). W.Bednarek and R.J.Protheroe suggested the interaction of the shock wave and the helical structure of the jet may cause this observed type of periodicity (Bednarek and Protheroe 1998).

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