ENERGY DEPENDENT X-RAY VARIABILITY OF THE TEV BLAZARS PKS 2155–304 AND MKN 421

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ABSTRACT We present the X-ray variability properties of the TeV blazars PKS 2155–304 and MKN 421 as observed with *Beppo*SAX and ASCA. The minimum timescales of $\sim$ 1000s are suggested. For PKS 2155–304 we found that the soft X-ray lags (relative to higher energies) are inversely correlated with the source intensity, i.e. the lag is longer when the source is fainter. In April 1998 a flare of MKN 421 was detected, during which higher energy X-rays lagged lower energy ones by $\sim$ 2500s. The origin of these lags is briefly discussed.

KEYWORDS: BL Lacertae objects: individual (PKS 2155–304 and MKN 421); X-rays: variability.

1. INTRODUCTION

PKS 2155–304 (z=0.117) and MKN 421 (z=0.031) are among the brightest BL Lac objects at the X-ray wavelengths and two of the few extragalactic TeV sources (Chadwick et al. 1999, Punch et al. 1992). *Beppo*SAX 1997 (SAX97) is the brightest, *Beppo*SAX 1996 (SAX96) the faintest and ASCA 1994 (ASCA94) intermediate state among the three observations of PKS 2155–304 (Zhang et al. 1999a). MKN 421 1998 (SAX98) observation is the highest state recorded (Fossati et al. 1999a).

2. STRUCTURE FUNCTION (SF) ANALYSIS

The first order SF of a time series $F(t)$ is a function of a timescale "τ", and is defined as: $SF(\tau) =< (F(t+\tau) - F(t))^2 >$ (Hughes, Aller & Aller 1992; Paltani

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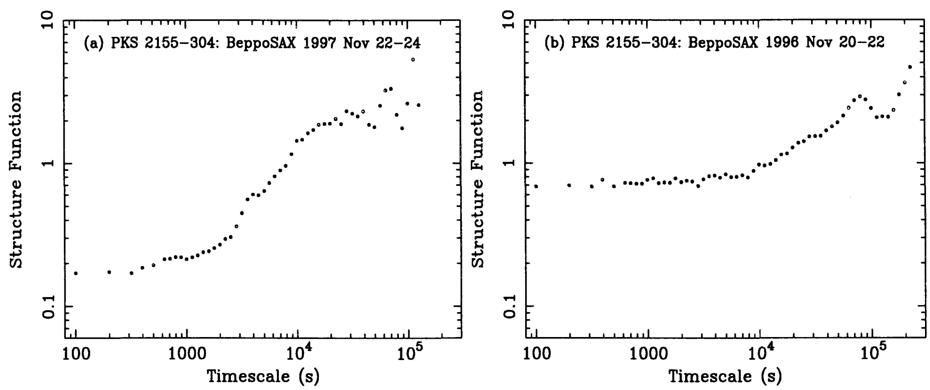

FIGURE 1. SFs (1.5−10 keV) of PKS 2155–304. The SF is normalized to the variance of the light curve. (a) SAX97; (b) SAX96.

1999). The SFs in the 1.5−10 keV band of the four light curves binned over 100s are presented in Figures 1 and 2, respectively.

Considering that observational length strongly affects SF at the largest timescales, the four SFs are compatible with a power law plus a constant representing the measurement uncertainties. However, they are flat up to different timescales possibly due to intrinsic or observational features from which we can not distinguish: if the source is brighter, measurement uncertainties will be comparatively lower, and the power law part of the SF will emerge from the noise at shorter timescale. Furthermore, the absence of steepening of the SFs prevent us from determining any physically meaningful minimum timescale of a process. However, as discussed by Paltani (1999), the absence of steepening of the SF suggests that the minimum timescale will be smaller than the timescale from which the power law emerge. Therefore, the upper limits of the minimum variability timescales would be $\sim$ 3000s, 4000s and 9000s for SAX97, ASCA94 and SAX96 observations of PKS 2155–304, and 3000s for MKN 421 SAX98, respectively. The minimum timescale down to $\sim$ 1000s is possible for the high state of PKS 2155–304 (SAX97) and MKN 421. In PKS 2155–304 whether these timescales correlate with the source brightness (a higher state corresponds to a smaller timescale) is worth studying. We mention this point because it has important consequences on the blazar radiation models.

3. CROSS CORRELATION ANALYSIS

We performed a detailed cross correlation analysis using two techniques suited to unevenly sampled time series: the Discrete Correlation Function (DCF, Edelson & Krolik 1988) and Modified Mean Deviation (MMD, Hufnagel & Bregman 1992). In addition, model-independent Monte Carlo simulations taking into account "flux randomization" (FR) and "random subset selection" (RSS) of the data sets (see

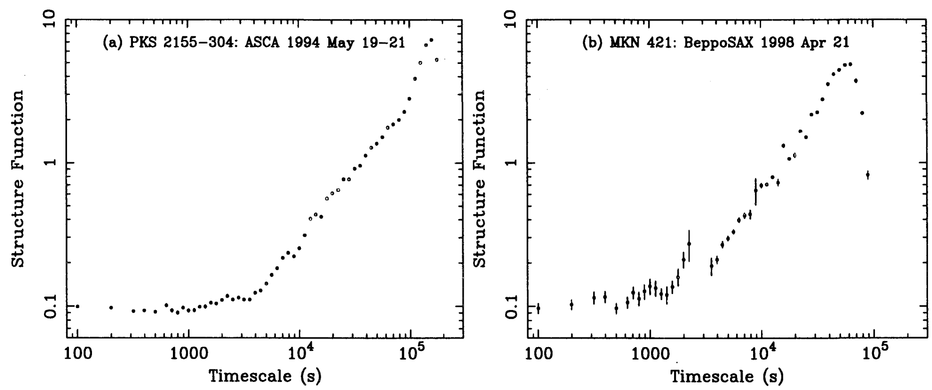

FIGURE 2. Same as Figure 1. (a) PKS 2155–304 (ASCA94) ; (b) MKN 421 (SAX98).

Peterson et al. 1998 for details) are used to statistically determine the significance of any time lag derived from DCF and MMD (see Zhang et al. 1999a for details). The cross correlated energy band is 0.1−1.5 keV vs 3.5−10 keV.

The analysis of PKS 2155–304 has been presented in Zhang et al. (1999a), the resulting soft time lags (which correspond to different brightness levels) are ~ 0.4, 0.8, 4.0 hours for the SAX97, ASCA94 and SAX96 observations, respectively. These findings indicate that the inter-band soft lags are variable, and inversely correlate with both the source intensities and the ratios of the maximum to minimum fluxes (see Figure 10 of Zhang et al. 1999a). The suggestive trend is such that the lag is longer when the source is fainter and less variable.

On the contrary, we find a negative time lag for the flare of MKN 421 on April 21 1998, i.e. the higher energy X-ray photons lagged the lower energy ones. We notice that this behaviour is *opposite* to the previous findings for this source and other HBLs. The best Gaussian fits result in negative lags of -0.82 ± 0.06 (DCF) and -0.60 ± 0.08 (MMD) hours, confirmed with high significance by the FR/RSS Monte Carlo simulations (Figure 3).

4. DISCUSSION

One of the main results of the analysis for PKS 2155–304 is the inverse correlation between lags and source intensities. This finding sheds light on the brightness dependence of time-dependent emission models and origin of lags (e.g., cooling, light travel times, particle injection/acceleration mechanism, ratio of underlying and flare components).

The new result for MKN 421 is the significant detection of a hard lag, *opposite* to that previously detected in HBLs. Interestingly, we notice that the 1998 April 21 flare represents the brightest state of MKN 421, and thus suggests the possibility that the hard lag follows the trend found for PKS 2155–304. Work is in progress

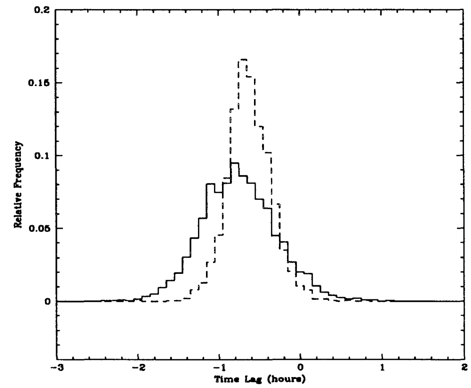

FIGURE 3. Cross Correlation Peak Distribution (CCPD) of FR/RSS simulations of MKN 421. The solid line represents the DCF, and the dashed line the MMD.

to examine this possibility (Zhang et al. 1999b), which would allow us to establish whether the acceleration/injection properties (e.g. Kirk, Rieger, & Mastichiadis, 1998) are related to the source brightness. The presence of a hard lag indicates that the flare evolution is driven by the acceleration/injection mechanism.

It is of primary importance to study together the evolution of time lags, X-ray spectra and energy shifts of the emission peaks. In at least a few HBLs when the source is more luminous, the spectra become harder, the synchrotron emission peak shifts to higher frequency and at least in the case of PKS 2155–304 the soft lag becomes shorter. The determination of the relative contribution of a flare and a steady emission component is also crucial to understand the underlying process at work (Fossati et al. 1999a; Fossati et al. 1999b).

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