BL Lac Phenomenon
ASP Conference Series, Vol. 159, 1999
L.O. Takalo and A. Sillanpää, eds.

Fast X-ray Variability of PKS 2155–304: A Cross Correlation Analysis

A. Treves

Universitá di Como, Via Lucini 3, I-22100 Como, Italy

Y.H. Zhang, A. Celotti

SISSA/ISAS, Via Beirut 2-4, I-34014 Trieste, Italy

F. Tavecchio, L. Maraschi

Osservatorio Astronomico di Brera, Via Brera 28, I-20121 Milano, Italy

G. Ghisellini, G. Tagliaferri

Osservatorio Astronomico di Brera, Via Bianchi 46, I-22055 Merate (Lecco), Italy

L. Chiappetti

IFCTR, C.N.R., Via Bassini 15, I-20133 Milano, Italy

E. Pian

ITESRE, C.N.R., Via Gobetti 101, I-40129, Bologna, Italy

C. M. Urry

STScI, 3700 San Martin Drive, Baltimore MD 21218, USA

1. Introduction

PKS 2155–304 is one of the prototypes of BL Lac objects. Its spectral energy distribution is known from the radio to the TeV band (e.g., Chiappetti et al. 1998; Chadwick et al. 1998). The emitted luminosity in the $\nu F(\nu)$ representation has two peaks, one in the soft X-rays and the other in the TeV region. This spectral shape, which is typical of High Frequency peaked (X-ray selected) BL Lacs, may be interpreted within the synchrotron self-Compton model, which attributes the first peak to synchrotron radiation of electrons which also produce the second peak via Compton scattering of the same synchrotron photons. The emission is relativistically boosted in the observer direction. A way of testing the model and characterizing its geometrical and kinematical properties is through the study of correlated variability in different bands. Because of its brightness, PKS 2155–304 is one of the few objects where such a study can be performed. In 1994, simultaneous observations with ASCA, EUVE and IUE (Urry et al. 1997) were carried out demonstrating the presence of a 1 day time lag between UV (2000 Å) and soft X-rays (100 Å), the latter lagging in turn by 1 day with respect to

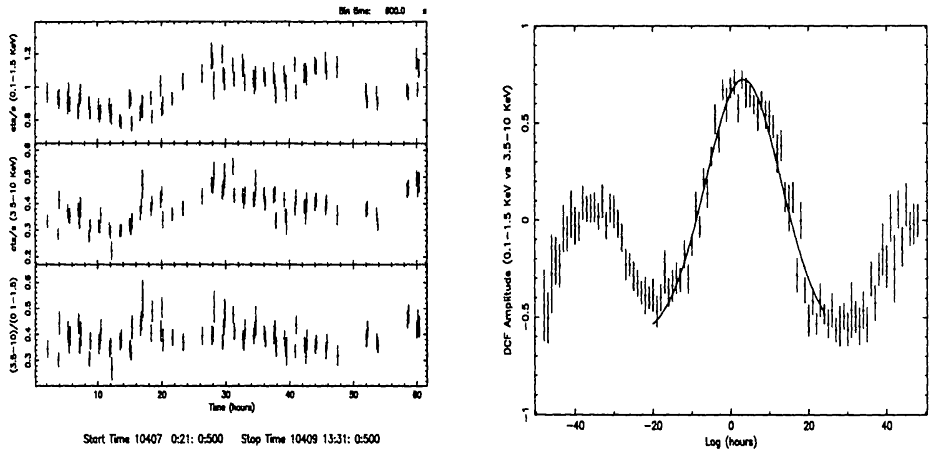

Figure 1. Left panel: the light curves and HR (from top to bottom). Right panel: DCF cross correlation with gaussian fit.

the 2-10 keV X-rays. A lag of 1 h was also found between the 0.5-1 and 2-10 keV photons (Makino et al. 1996). The behaviour of the source was clearly different from that observed in 1991 (Edelson et al. 1995), when the comparison of IUE and ROSAT data demonstrated that the lag between UV and 1-4 keV photons was of the order of 2 hr. Here we report on the search and accurate study of lags in two long X-ray observations performed with the *Beppo*SAX satellite. The first one was accomplished during the performance verification (PV) phase of the satellite in Nov. 1996 (Giommi et al. 1998), the second one in Nov. 1997, in correspondence of a high activity phase of the source in gamma-rays (Maraschi et al. 1998; Chiappetti et al. 1998). *Beppo*SAX covers a broad energy interval extending from 0.1 to 200 keV and it is therefore apt for searching for lags or leads within the X-ray band. The cross correlation technique requires of course that the light curves are binned on time intervals smaller than the searched lags. We are therefore practically limited to the use of the 0.1-10 keV band, which is covered by the low energy concentrator spectrometer (LECS, 0.1-10 keV) and the medium energy concentrator spectrometers (MECS 2-10 keV). For brevity here we focus on the results relative to the *Beppo*SAX PV phase observations only. In a forthcoming paper (Zhang et al., in preparation) we will also report on a similar analysis applied to the Nov. 1997 *Beppo*SAX and 1994 ASCA data retrieved from the archives.

2. Light Curves

The procedure applied for producing the *Beppo*SAX light curves is discussed in detail in Chiappetti et al. (1998). Fig. 1 shows the LECS and MECS count rates in the 0.1-1.5 keV and 3.5-10 keV energy bands and the hardness ratio (HR) between them. The HR shape is similar to that of the light curves, a direct indication of the lead of higher energies.

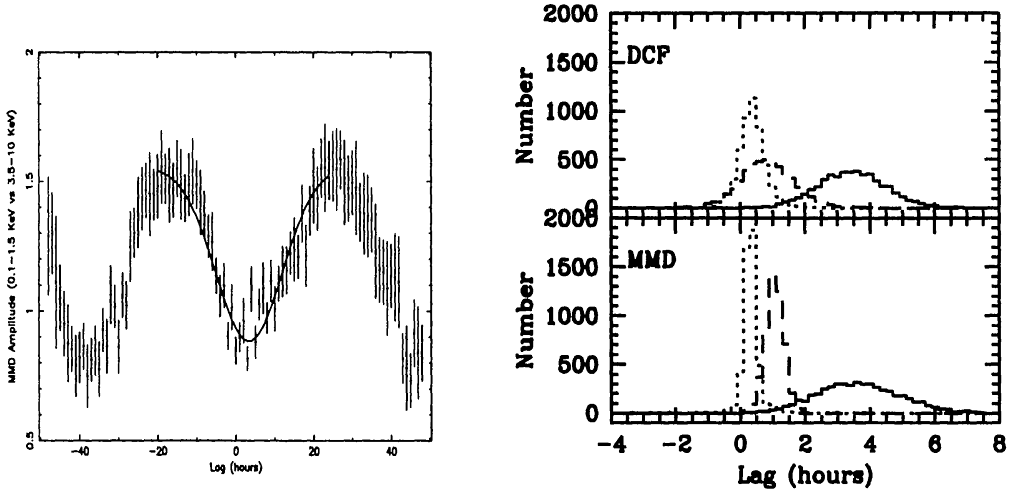

Figure 2. Left panel: MMD with gaussian fit. Right panel: FR/RSS Simulations. The solid line refers to the SAX 1996, the dotted line to the SAX 1997 and the dashed line to the ASCA 1994 data.

3. Cross Correlation Analysis

3.1. Discrete Correlation Function (DCF)

The DCF method is described in Edelson & Krolik (1988). The DCF results are reported in Fig. 1; the chosen DCF binning size was 3600 sec and the peak was fitted with a Gaussian plus a constant. As lag between the two bands we took the Gaussian center, rather than the DCF maximum (see the arguments of Edelson et al. 1995 and Peterson et al. 1998). Table 1 reports the lag and the 1σ uncertainty (for all of the three sets of observations).

3.2. Modified Mean Deviation (MMD)

The MMD technique was introduced by Hufnagel & Bregman (1992). The maximum correlation corresponds to a minimum of the MMD. The MMD and relative Gaussian fit are given in Fig. 2 (MMD bin sizes are the same of the DCF). The results are summarized in Table 1.

3.3. Monte Carlo simulations

In order to estimate the dependence of our findings on photon statistics we followed the prescriptions of Peterson et al. (1998) introducing "flux randomization" (FR) and "random subset selection" (RSS). The DCF and MMD procedures were then applied to 5000 pairs of Monte Carlo simulated light curves. The distribution of the lags are reported in Fig. 2. The mean lags and their uncertainties are obtained by fitting these distributions with Gaussians (see Table 1). For comparisons, here we also include the results of this same analysis for the 1997 *Beppo*SAX and 1994 ASCA data.

Table 1. Summary of the lags (hours)

Obs.	DCF(1σ)	MMD(1σ)	FR/RSS DCF(1σ)	FR/RSS MMD(1σ)
SAX 1996	3.26(0.16)	3.39(0.38)	3.44(1.08)	3.66(1.29)
SAX 1997	0.49(0.08)	0.33(0.07)	0.37(0.47)	0.32(0.33)
ASCA 1994	0.53(0.15)	1.09(0.07)	0.83(1.32)	1.06(0.28)

4. Discussion

It is apparent from Table 1 that the lags estimated with the two techniques are fully compatible within the uncertainties of the Monte Carlo results. The presence of a soft lag of 3 hours is rather clear in the first *Beppo*SAX observation. The second *Beppo*SAX and ASCA observations indicate a shorter lag which is consistent with zero. Therefore the indication is that the lags are variable. The variability of the lags is reminiscent of the variability between the 1991 and 1994 states of the source mentioned in the Introduction.

Time dependent models of BL Lac emission taking into account changes in particle spectrum, energy losses, diffusion, and relativistic propagation effects have been recently proposed (see Kirk et al. 1998; Dermer 1998; Chiaberge & Ghisellini 1998; Makino, this conference). The soft lags appear qualitatively consistent with the models.

Acknowledgments. YHZ and AC acknowledge the Italian MURST for financial support.

References

Chadwick, P. M., et al. 1998, ApJ, submitted
Chiaberge, M., & Ghisellini, G. 1998, M.N.R.A.S., submitted
Chiappetti, L., et al. 1998, ApJ, to be submitted
Dermer, C. 1998, astro-ph/9805289
Edelson, R. A., et al. 1995, ApJ, 438, 120
Edelson, R. A., & Krolik, J. H. 1988, ApJ, 333, 646
Giommi, P., et al. 1998, A&A, 333, L5
Kirk, J. G., et al. 1998, astro-ph/9801265
Makino, F., et al. 1996 MPE Rep. 263, p. 413
Maraschi, L., et al. 1998, astro-ph/9808177
Peterson, B. M., et al., 1998, PASP, 110, 660
Urry, C. M., et al. 1997, ApJ, 486, 799