

Short-timescale Variability in the Broadband Emission of the Blazars Mkn421 and Mkn501

M.J. Carson¹, B. McKernan¹, T. Yaqoob², D.J. Fegan¹

¹*Department of Physics, University College Dublin, Dublin 4, Ireland*

²*Laboratory for High Energy Astrophysics, Code 660.2 Goddard Space Flight Center, Greenbelt, MD 20771*

Abstract

We analyse *ASCA* x-ray data and Whipple γ -ray data from the blazars Mkn421 and Mkn501 for short-timescale variability. We find no evidence for statistically significant ($> 3\sigma$) variability in these data, in either source, on timescales of less than ~ 10 minutes.

1 Introduction

The recently detected TeV radiation from the Blazars Mkn421 and Mkn501 may be Comptonized synchrotron radiation (Comastri *et al.*, 1997) or Comptonized ambient radiation (Sikora *et al.*, 1997) or some mixture of the two. Alternatively, the γ -radiation may result from a proton-initiated cascade (Beall & Bednarek, 1998). Models of the γ -radiation predict large qualitative differences in some source parameters, so a search for short-timescales of variability in these AGN may be important in constraining models of emission and ultimately in distinguishing between them. Short timescale variability may also constrain quantum gravity effects predicted by some string theories (Amelino-Camelia *et al.*, 1998).

Variability studies (using the χ^2 -test) have been carried out on data from Mkn501 and Mkn421. The shortest observed timescales of variability in TeV γ -rays correspond to doubling times in rapid flares of ~ 15 minutes for Mkn421 (McEnery, 1997) and ~ 2 hours for Mkn501 (Quinn *et al.*, 1999) which may indicate a variability cut-off or a lack of instrumental or method sensitivity to real variability at timescales shorter than these. The shortest timescales so far observed in these sources at x-ray energies are ~ 1 day for Mkn501 (Kataoka *et al.*, 1999) and 0.5-1.0 days for Mkn421 (Takahashi, Madejski & Kubo, 1999).

The analysis reported here involves a broadband variability study of Mkn501 and Mkn421 using the Excess Pair Fraction (EPF) technique (Yaqoob *et al.*, 1997). We analyse non-simultaneous Whipple TeV γ -ray data and *ASCA* x-ray data from these blazars.

2 EPF applied to x-ray data

ASCA (Tanaka *et al.* 1994) observed Mkn 421 and Mkn 501, obtaining moderate energy resolution spectra in the 0.5–10 keV band, with a time-resolution of better than 2 s for two of the four instruments onboard (4 s for the other two). Mkn 421 was observed on eighteen occasions between 1993, May 10 and 1997, June 3, with a total exposure time of $\sim 240 \times 10^3$ s. The 1996 data do not overlap with the TeV data reported in this paper. Mkn 501 was observed on four occasions between 1996, March 21 and 1996, April 2, with a total exposure time of $\sim 49 \times 10^3$ s. Additional *ASCA* observations of both sources exist but only those made of the dates mentioned above were in the public archive at the time of writing. An excellent account of the Mkn 421 *ASCA* observations and results can be found in Takahashi, Madejski, and Kubo (1999) and the *ASCA* results for Mkn 501 can be found in Kataoka *et al.*(1999). We re-analysed the *ASCA* data ourselves, which were re-

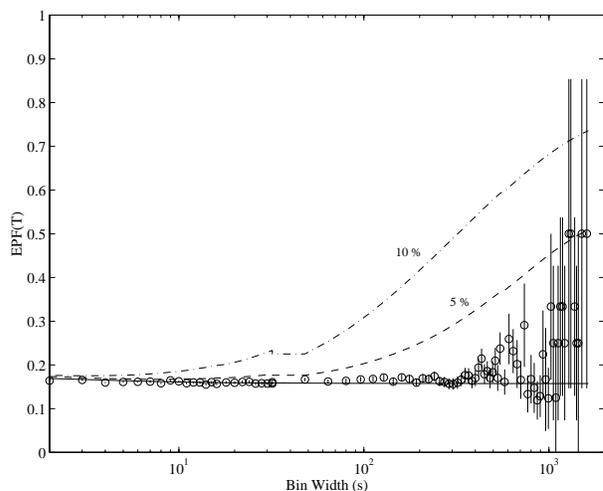


Figure 1: EPF for *ASCA* x-ray data on Mkn421.

duced in the same manner as described in Yaqoob *et al.*(1998). We made EPF for each source following the methods described in Yaqoob *et al.*(1997), averaged over all the available data sets.

The results for both sources are shown in Figs. (1) & (2). The solid, dotted and dashed curves show theoretical EPF for a source with 0%, 5%, and 10% random amplitude variability respectively. The curves were generated as described in detail in Yaqoob *et al.* 1997. It can be seen that in Mkn 421 we can rule out variability at the 5% level with a confidence level greater than 3σ from ~ 500 s down to timescales of ~ 11 s. (Note: The kink at 32 s is due to only two of the four ASCA instruments being used below this timescale because the two Solid State Spectrometers have less timing resolution than the two Gas Imaging Proportional Counters). For Mkn 501, for which much less data are available, we can rule out variability at the 10% level with a confidence level greater than 3σ from ~ 400 s down to timescales of ~ 32 s.

3 EPF applied to γ -ray data

TeV data are recorded by the Whipple Observatory Imaging Atmospheric Cerenkov Telescope (IACT). The IACT uses the well-established Extensive Air Shower (EAS) technique to indirectly observe very high energy γ -rays from sources such as AGN jets and supernova remnants (Cawley *et al.*, 1990). Most atmospheric showers are due to the collision of high energy cosmic rays (hadrons or leptons), therefore the parent γ -ray data, as observed by the IACT, have a very small signal to noise ratio. Parameter cuts are used to eliminate most of the noise whilst retaining at least 50% of the signal. The TeV data are typically recorded in ~ 28 minute intervals, at different elevations and during various weather conditions. Only those data sets with the most stable raw count rates were used. The Mkn421 data were taken from the period April 1996-May 1996, during which time the most significant flaring event ever seen at this energy was observed. The Mkn501 data were taken from the period April 1997- May 1997, during which time this AGN was at its most active since its discovery at this energy in 1995. The presence of strong flaring within these data is important for statistical purposes as the count rate from the AGN increases from typically $\leq 1\gamma \text{ min}^{-1}$ to $\sim 10\gamma \text{ min}^{-1}$ during a strong flaring state.

Fig. (3) shows EPF for Mkn421. Approximately 1760 minutes of data are used in this analysis at TeV en-

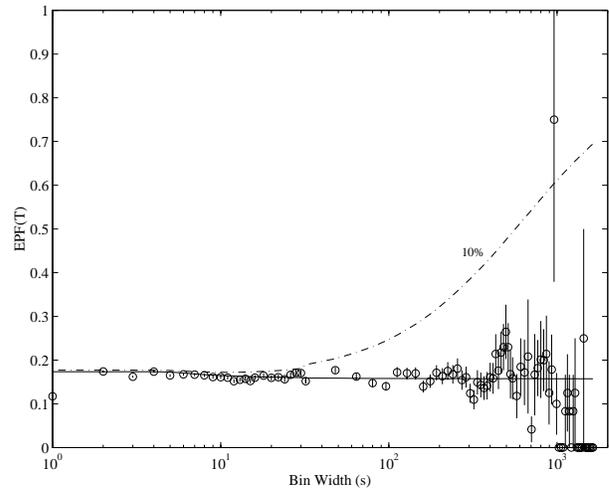


Figure 2: Open circles show the Excess Pair Fraction (EPF) computed from all the ASCA Mkn 501 observations (see text).

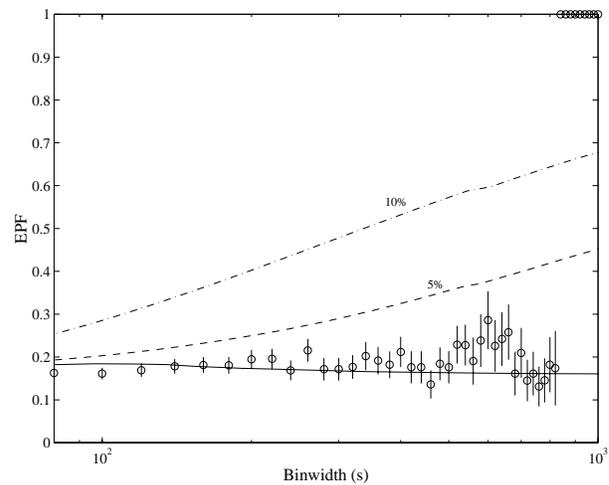


Figure 3: Open circles show EPF for Whipple Mkn421 data. The solid line is the theoretical EPF expected from a constant source and dashed lines are the theoretical EPF for 5% and 10% random amplitude variability.

ergies. None of the data points are greater than 3σ from that of a theoretical constant source with the same mean count rate. Because of the 28 minute data binning only timescales less than 14 minutes can be considered using this technique. The γ -ray rate ($\sim 3\gamma\text{min}^{-1}$) prevents us probing timescales much lower than ~ 200 seconds. Fig. (4) shows EPF for Mkn501 with approximately 1900 minutes of data. Again none of the data points are greater than 3σ from that of a constant source with the same mean count rate indicating a lack of significant variability in this source below ~ 10 mins. Here the rate is $\sim 9\text{min}^{-1}$ and so the lower timescale below which the statistics become too poor is ~ 100 seconds. Thus, we can rule out variability in both sources below ~ 10 minutes at a confidence level $> 3\sigma$ at the 10% variability level.

4 Discussion and Conclusions

Our results thus far show that there appears to be no statistically significant variability in either of the two AGN, below timescales of ~ 600 s. From these results we conclude that either the statistics of the present data are insufficient to establish significant variability or the data does not vary on these timescales. If we assume that the source is not varying on timescales shorter than 10 minutes then we can estimate the minimum size of the emission region: the Doppler beaming factor is given by $D = 1/(1+z)\Gamma_b(1-\beta\cos\theta)$ where z is the redshift of the source, Γ_b is the Lorentz boost, $\beta = v'/c$ (where v' is the velocity of the emitting region) and θ is the angle between the jet axis and the observer. Causal arguments require that the size of the emission region R_{em} is constrained to satisfy

$$R_{em} \leq c\delta t \frac{D}{(1+z)} \quad (1)$$

Where δt is the observed variability timescale (> 10 minutes here). For Mkn421 $z = 0.031$, $D \approx 13.8$ and so $R_{em} \approx 2.5 \times 10^{14}$ cm. If the emission region is located in the putative jet then given a jet opening angle of 3° , the emission region is at least 4.7×10^{15} cm from the base of the jet, or assuming a black hole mass of $\approx 10^8 M_\odot$, the emission region is at least ~ 160 gravitational radii from the black hole.

5 Acknowledgements

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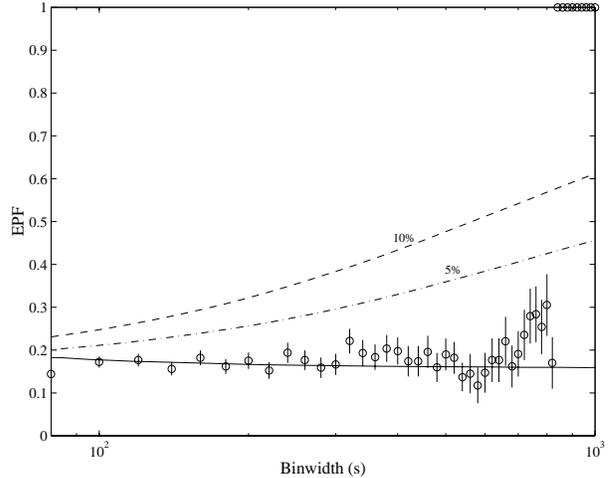


Figure 4: EPF for Whipple Mkn501 data.

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Yaqoob, T., *et al.*1998, ApJ 505, L87