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COMPTEL MeV Observations of the TeV Sources Markarian 421 and Markarian 501

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Abstract

The COMPTEL experiment aboard the COMPTON Gamma-Ray Observatory (CGRO) has observed the prominent TeV-blazars Mkn 421 and Mkn 501 many times between the start of its mission in April '91 and December '98. This paper reports first COMPTEL results from mainly time-averaged (CGRO Cycles) data. No evidence for both sources is found up to the end Cycle VI. However, the sum of all 10-30 MeV Cycle VII data shows a weak (3.2σ detection) MeV-source being positionally consistent with Mkn 421. During Cycle VII Mkn 421 was rather active at TeV-energies. Due to the lack of other known γ-ray sources in this sky region, we consider Mkn 421 as the most likely counterpart for this γ-ray emission. However, its connection cannot be proven by COMPTEL.

1 Introduction:

The discovery by the CGRO experiments that blazars sometimes radiate a large or even the major fraction of their luminosity at γ-ray energies marked a milestone in our knowledge on these powerful sources. Now, after 8 years of operation, roughly 80 blazars have been detected by EGRET at γ-ray energies above $\sim$100 MeV (e.g. Hartman et al. 1999). COMPTEL, covering the soft γ-ray range (0.75-30 MeV) has detected 9 of these EGRET blazars (Collmar et al. 1999).

During recent years some blazars have been discovered to emit even at TeV-energies by the Whipple Observatory: the blazars Mkn 421 (Punch et al. 1992), Mkn 501 (Quinn et al. 1996), and 1 ES 2344+514 (Catanese et al. 1998). The most prominent ones are Mkn 421 and Mkn 501, which have been detected many times by Whipple and confirmed by other TeV-experiments like the HEGRA Cherenkov telescopes (e.g. Aharonian et al. 1999). Despite their (occasional) prominence at TeV-energies – during flaring periods Mkn 501 was the brightest TeV-source in the sky – they are weak EGRET sources. Mkn 421 shows a weak flux in the EGRET band and Mkn 501, at the time of its TeV-discovery, was not detected at all by EGRET. A common feature of all TeV-blazars is their extreme variability on time-scales of years, days, hours, or even minutes.

COMPTEL, along the course of its now 8-year mission, has had the prominent TeV-blazars Mkn 421 and Mkn 501 several times within its field-of-view. The complete set of data (April '91 to Nov. '98) on these sources has been analysed. In this paper we will concentrate on time-averaged results, i.e. results of combined data over periods of typically one year.

2 Observations and Data Analysis:

CGRO observations are organized in so called Cycles (or Phases) which last for a time period of roughly one year, consisting of many (30 - 40) individual pointings (called Viewing Periods: VPs), which typically last for two weeks. Table 1 provides the COMPTEL exposures on both sources for the individual CGRO cycles. It clearly shows that Mkn 421 was favorably located for COMPTEL in Cycle VII. This is due to its proximity ($\sim$25^o) to SN 1998bu which was a major COMPTEL target in 1998.

We have applied the standard COMPTEL maximum-likelihood analysis method (e.g. de Boer et al. 1992) to derive detection significances, fluxes, and flux errors of γ-ray sources in the four standard COMPTEL energy

Table 1: COMPTEL exposures on Mkn 421 and Mkn 501 in individual CGRO cycles. The table provides the time periods of the individual cycles, and for both sources the number of days within 30^o and 20^o of the COMPTEL pointing direction and the effective exposures (net observation time with 100% COMPTEL efficiency).

CGRO Phase/Cycle	Time Intervals yy/mm/dd - yy/mm/dd	Mkn 421 [Days $<30^o/20^o$]	Mkn 421 Eff. Exp.	Mkn 501 [Days $<30^o/20^o$]	Mkn 501 Eff. Exp.
I	91/05/16 - 92/11/17	35/14	8.19	9/9	5.76
II	92/11/17 - 93/08/17	48/21	6.61	14/14	3.49
III	93/08/17 - 94/10/04	21/21	11.01	0/0	2.66
IV	94/10/04 - 95/10/03	14/14	3.96	8/8	1.89
V	95/10/03 - 96/10/15	14/14	2.37	27/27	10.06
VI	96/10/15 - 97/11/11	0/0	0.00	28/6	7.18
VII	97/11/11 - 98/12/01	108/25	22.43	23/9	10.39

bands (0.75-1 MeV, 1-3 MeV, 3-10 MeV, 10-30 MeV), and a background modelling technique which eliminates any source signature but preserves the general background structure (Bloemen et al. 1994). The source fluxes for both sources have been derived by a flux fitting procedure which iteratively determines the flux of one or more potential sources and simultaneously a background model which takes into account the presence of possible sources. As there are no known nearby γ-ray sources or source candidates, for the case of Mkn 421 no other source was included in this procedure, while for the case of Mkn 501 the prominent EGRET quasar 4C+38.41, which is only $\sim 4^o$ away, was included as a second source. Because Mkn 421 (l/b: 179.8/65.0) and Mkn 501 (l/b: 63.6/38.9) are located at high galactic latitudes, the present analyses have been carried out consistently in local coordinate systems, i.e. centered on each source.

3 Results:

3.1 Markarian 421: Up to the end of CGRO Cycle VI (November '97) no convincing evidence for Mkn 421 could be found in any of the four standard COMPTEL energy bands in the different CGRO cycles. However, in the 10-30 MeV map of CGRO Cycle VII a source-like feature appears which is positionally consistent with Mkn 421 (Fig. 1). The detection significance at the position of Mkn 421 is formally 3.2σ assuming χ^2_1-statistics for a known source, i.e. close to the detection threshold. We checked the 3rd EGRET catalogue (Hartman et al. 1999) for γ-ray sources in this region. Apart from Mkn 421, the catalogue lists no other source which could be responsible for this γ-ray emission. Therefore, we consider Mkn 421 as the most likely candidate. This is supported by the fact, that in 1998 Mkn 421 was unusually active at TeV-energies, sometimes even brigther than the Crab (Aharonian et al. 1999). However, a different origin for this γ-ray emission than Mkn 421 cannot be excluded. EGRET cannot help to resolve this issue, because it observed this sky position simultaneously only for 4 out of the 108 COMPTEL days (Table 1): either the pointings were too far off for its narrow-field-of-view mode or EGRET was switched off. Applying the procedure described in Section 2, fluxes from the position of Mkn 421 have been derived. In addition to the 3σ result in the 10-30 MeV band of the Cycle VII data, there is a 2σ flux point derived in the 3-10 MeV band for this time period. Below 3 MeV the data are consistent with noise resulting in upper limits only. In Figure 1 these flux values are compared to the time-averaged 1997-1998 HEGRA TeV-spectrum (Aharonian et al. 1999). The authors provide the spectral slope for the year 1998 individually (α: -3.00$\pm$0.05) but not the flux normalisation. They note that the spectral slopes in both years are consistent within statistics. The comparison shows that Mkn 421 (if responsible for the emission) radiated in 1998 on average more power at MeV-energies than at TeV-energies. In addition, the MeV spectral points are several orders of magnitudes below the power-law extrapolation of the TeV-spectrum, proving that the TeV-spectrum has to bend over above 30 MeV. The last conclusion is also valid of course, if the observed γ-rays are not connected to Mkn 421. We like to note, that a large fraction of the COMPTEL

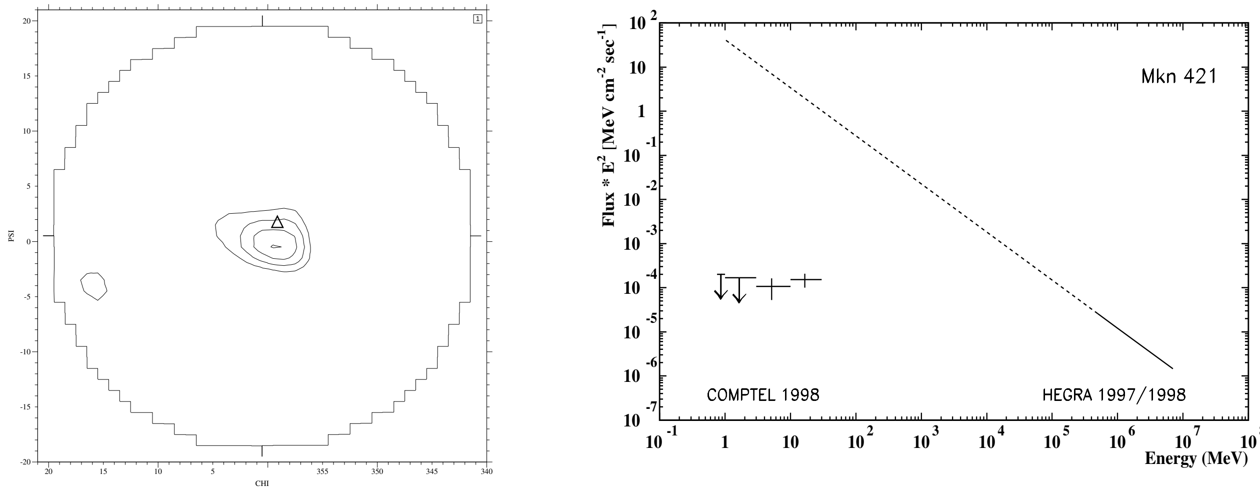

Figure 1: Left: The 10-30 MeV maximimum likelihood skymap around the position of Mkn 421 ($\triangle$) in local coordinates (χ/ψ) for the sum of all Cycle VII data. The contour lines start at a detection significance of 2.5σ (χ^2_1-statistics) with a step of 0.5σ. The γ-ray emission is positionally consistent with Mkn 421. Right, comparison of the COMPTEL Cycle VII flux results to the average 1997-1998 HEGRA TeV-spectrum (Aharonian et al. 1999). The solid line shows the energy range (500 GeV to 7 TeV) of the HEGRA measurements, and the dashed line the spectral extrapolation of the reported power-law shape towards lower energies.

Cycle VII exposure on Mkn 421 was collected during times (July to September 1998), when the source was inaccesible for TeV-observations.

3.2 Markarian 501: Up to the end of CGRO Cycle VII (December 1998) no convincing evidence for Mkn 501 could be found in any of the four standard COMPTEL energy bands in the different CGRO Cycles. At TeV-energies Mkn 501 showed its largest activity so far during the observational period in 1997 (e.g. Quinn et al. 1999). To be quasi-simultaneous with that, we combined all COMPTEL Cycle VI data on Mkn 501 and derived the upper limits for its MeV flux. Unfortunately, only 6 days (a CGRO ToO during April 1997) of COMPTEL observations are directly simultaneous to the observed TeV-flaring period. The COMPTEL 1997 upper limits are compared to the time-averaged 1997 TeV-shape as observed by the Whipple telescope in Figure 2. The COMPTEL upper limits are $\sim$2 orders of magnitude below the extrapolation for an assumed power-law shape at TeV-energies, requiring spectral bending, but still allowing for a luminosity in the MeV-band roughly equal to that detected in the TeV-band. Evidence for spectral bending was recently also found in the TeV-data itself (e.g. Samuelson et al. 1998). The COMPTEL points are consistent with the extrapolation of that shape towards lower energies. As mentioned above, in April 1997 a multiwavelength campaign on Mkn 501 was carried out, where CGRO participated for 6 days (April 9-15, 1997) in a target-of-opportunity observation. COMPTEL has not detected the blazar within this short observation period. The COMPTEL upper limits are shown in Figure 2, together with simultaneous flux measurements (Catanese et al. 1997) from neighboring high-energy bands. The COMPTEL upper limits are consistent with these measurements, however do not provide any further constraints.

4 Summary and Conclusions:

We present first COMPTEL MeV-results of the prominent TeV-blazars Mkn 421 and Mkn 501. So far, the analysis has been carried out in the four standard energy bands for individual CGRO VPs and individual CGRO cycles. Up to the end of CGRO Cycle VI (November 1997), no evidence for Mkn 421 was found. However, the combined Cycle VII 10-30 MeV data show evidence (although near the detection threshold) for a γ-ray source which is positionally consistent with Mkn 421. As there are no other known γ-ray sources in that sky

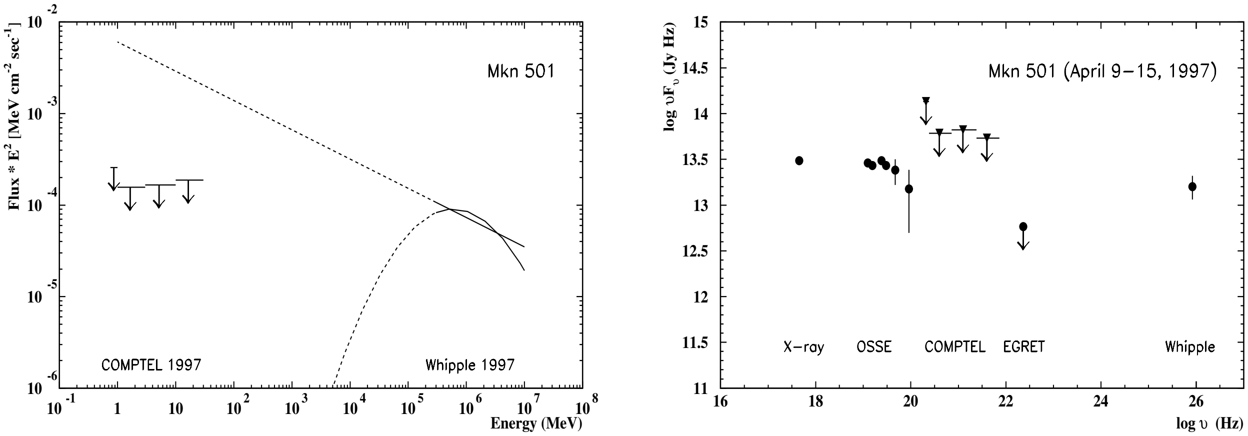

Figure 2: Left: Comparison of the average COMPTEL Cycle VI upper limits of Mkn 501 with the quasi-simultaneous average 1997 TeV-spectrum as published by the Whipple collaboration (Samuelson et al. 1998). The solid lines show the energy range of the Whipple measurements (300 GeV - 10 TeV) and the dashed lines the spectral extrapolations for the power-law and curved spectral shape towards lower energies. Right, the COMPTEL upper limits are included in a simultaneously measured broad-band spectrum of Mkn 501 (Catanese et al. 1997). The campaign was carried out (April 9-15, 1997) during an active TeV-period of Mkn 501.

region, we consider the TeV-blazar as the most likely counterpart. If this γ-ray emission really originates from Mkn 421, this would be an interesting result. Broad-band spectra for flaring TeV-blazars indicate a spectral minimum near the COMPTEL and EGRET bands (e.g. Fig. 2), i.e. they should be located in the ”spectral valley” between the peaks of the assumed synchrotron and inverse Compton (IC) emission components. This result would mean that either the synchrotron emission moved up to the highest energies ever observed, or the IC emission at MeV-energies was as high as never observed before for any TeV-blazar which would be the most likely explanation in our mind, or something else (e.g. a combination of both) has happened. Eventually, multiwavelength spectra might help to resolve this issue. No convincing evidence for Mkn 501 is found in any of the analysed data. Derived upper limits, which are quasi-simultaneous with the large TeV-flaring period in 1997, require a spectral bending for a TeV power law spectrum, and are consistent with the extrapolation of a reported curved TeV-spectrum. COMPTEL participation in a multiwavelength campaign resulted in upper limits which are consistent with the simultaneous measurements in the neighboring energy bands, however do not provide any further constraints.

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