Multi-wavelength observations of the TeV Blazars Mkn 421, 1ES1959+650, and H1426+428 with the HEGRA Cherenkov telescopes and the RXTE X-ray satellite

D. Horns for the HEGRA collaboration

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Abstract. Recent results obtained with the HEGRA system of imaging Cherenkov telescopes on the TeV emission of the Blazars Mkn 421 (z = 0.030), 1ES1959+650 (z = 0.047), and H1426+428 (z = 0.129) are reported. For Mkn 421, a close connection of the average flux level and spectral shape has been observed during the periods of increased activity in the years 2000 and 2001. Simultaneously taken data with the RXTE X-ray satellite reveal a complex light curve at X-ray and TeV energies. After a deep exposure of 94 hrs, the object 1ES1959+650 was detected at the significance level of 5.4σ with a soft energy spectrum following a power-law with a photon-index of 3.3 ± 0.7. During recent observations in May 2002, the source has shown increased activity with indications for a flattening of the energy spectrum. The high energy peaked Blazar H1426+428 has recently been identified as a source of TeV photons. Since the source is fairly distant (z=0.129), absorption of TeV photons due to pair-production on the optical and near infrared extragalactic light becomes important and should leave a signature in the observed TeV energy spectrum. Notably, the TeV energy spectrum determined with the HEGRA system of Cherenkov telescopes agrees with the expectation of a strongly absorbed source spectrum.

1. Introduction

The surprisingly large number of Active Galactic Nuclei discovered by the EGRET instrument on-board the Compton Gamma Ray observatory has fueled interest in the search for TeV emission from these sources. Particularly, the Blazars (flat radio spectrum quasars and BL Lac objects) among the EGRET identified sources have raised the interest of observers at energies accessible to ground based imaging air Cherenkov telescopes (IACTs). All currently known extragalactic sources of TeV γ-radiation belong to the class of nearby BL Lac objects. These sources are believed to produce γ-rays emanating from a population of energetic non-thermal particles which move relativistically along the jet-axis aligned with the line of sight. The nature, origin, and initial acceleration mechanism of these relativistic particles are however not yet identified.

The observations of Blazars at TeV energies have so far helped to constrain the size of the emission region and set lower limits to the relativistic Doppler factor
that one has to assign to the bulk motion of the emitting region.
In Section 2., We will summarize results on three Blazars with different red
shift (Mkn 421, 1ES1959+650, H1426+428) obtained with the HEGRA system
of IACTs. Initial results of an extended RXTE campaign to observe Mkn 421
simultaneously at X-ray and TeV energies will be reported in Section 3.

2. Observations with the HEGRA CT-System

2.1. Mkn 421 ($z = 0.030$)
This object has been intensively monitored with the HEGRA IACTs since 1997
(Aharonian et al. 1999). Until June 2000, the source has remained at a low
flux level. However, strong activity has been observed during the years 2000
and 2001, where the source remained at an overall flux level of approximately
twice the flux of the Crab Nebula (Aharonian et al. 2002b). The energy spectra
for different average flux levels have been derived (Fig. 1a), indicating at all
flux levels a curvature well described by an exponential cut-off at $3.6 \pm 0.3$ TeV.
The observations reveal clear evidence for a correlation of the spectral shape
and the flux level. The spectrum becomes harder during higher fluxes and
softens at lower fluxes. The correlation of photon index and flux is shown in
Fig. 1b. We have observed diurnal variations of the energy spectrum. Plotting
the hardness-ratio and integral fluxes in a diagram, we see a clock-wise behavior
in the hardness-ratio vs. flux diagram (see Fig 1c).

2.2. 1ES1959+650 ($z = 0.047$)
A deep observation with HEGRA of 94 hrs in 2000 and 2001 has revealed this
object as a weak TeV source, confirming earlier tentative claims (Nishiyama
et al. 1999). The integral flux level averages at 5% of the flux observed from
the Crab-Nebula. The significance of the detection is at 5.4$\sigma$. The energy
spectrum extracted from these data shows a steep source spectrum well described
by a power-law with photon index $\alpha = 3.2 \pm 0.3$ (Aharonian et al. 2002c).
Recent observations in May 2002 showed strong variations of the flux level with
peak values being more than an order of magnitude higher than the previous
detection in the years 2000 and 2001. The preliminary energy spectrum during
the flare exhibits pronounced curvature and deviates significantly from the steep
spectrum seen during the quiescent state (see Fig. 2).

2.3. H1426+428 ($z = 0.129$)
This object was discovered by HEAO observations and was later identified as
a BL Lac object and confirmed as a steady and bright X-ray source in Ein-
stein and EXOSAT observations (Remillard et al. 1989). Furthermore, during
Beppo-SAX observations in 1999 (Costamante et al. 2001), the X-ray spectrum
has been found to be very hard and to extend up to $\approx 100$ keV without indication
of a steepening. The source is a member of the class of extreme Synchrotron BL
Lacs (Costamante et al. 2001) with features similar to those observed at X-rays
from Mkn 501 during the high-state in 1997 (Pian et al. 1998). The HEGRA
system of IACTs has been used to observe the source in 1999 and 2000 for a
total of 44.4 hrs. An excess with a significance of $5.8\sigma$ from the direction of
Figure 1. For different integral flux levels observed from Mkn 421, spectral fits have been applied to the data (a) and the ratio of energy spectra have been calculated. While keeping the position of the exponential cut-off constant at 3.6 TeV, the photon index shows a correlation with the flux level (right panel). For a comparison, the same fit has been applied to archival data of 1997/1998. For two successive nights, variations of the hardness ratio have been observed, following a clock-wise pattern in a Hardness-Flux diagram (lower right panel).

H1426+428 reveals this source as an emitter of TeV emission. No strong indication of variability was found (Aharonian et al. 2002a).

The energy spectrum has been extracted (Fig. 3a). Given the red-shift of the object of $z = 0.129$ and the expected diffuse extragalactic background light (EBL) at wavelengths between 1 and 15 µm (see Fig. 3b), considerable absorption of the TeV photons is to be expected (see Fig. 3c). However, given the uncertainty of the currently available measurements and estimates of the strength of the EBL, the optical depth at 5 TeV is roughly constrained to be $2 < \tau < 5$. In any case, the observed spectrum is expected to be modified by absorption features. We have adapted a model for the EBL similar to one calculated by Primack (2001) to a current compilation of measurements. This model of the EBL predicts a steep slope of the SED between 2 and 15 µm. The steep slope produces a flattening of the optical depth between 2 and 8 TeV which would lead to a flattening of the observed spectrum (see Fig. 3c). Indeed, such a flattening is consistent with the observed data points (see again Fig. 3a). Remarkably, the 5 TeV data point itself shows the highest significance which is consistent with a
very hard spectrum in this energy-region. The recently published spectral data at lower energies (Petry et al. 2002, Djannati-Ataï et al. 2002) hint at a steep slope with a photon index of $3.5$ below $\approx 2 \, \text{TeV}$. This would be consistent with our low energy data and would support our claim about a spectral flattening at higher energies as it is expected for a heavily obscured TeV-spectrum.

3. Observations with RXTE

In March 2001, the RXTE pointed instruments have been used to monitor Mkn 421 continuously for one week. During this time, the flux showed strong flux and spectral variability at TeV and X-ray energies. A more in depth analysis of the data are in preparation. Here, we present the combined X-ray and TeV light-curve of Mkn 421 during the monitoring (see Fig. 4). The flux variations show a complex pattern at both energy regions. Notably, a tight correspondence of flaring activities is not evident.

4. Conclusion

The HEGRA system of Cherenkov telescopes continues to successfully explore the wealth of Blazar phenomena at the highest energies. So far, four BL Lac objects have been detected by HEGRA and the energy spectra have been studied in detail. Here, we have presented results on three of the four BL Lac objects (not including Mkn 501) that have been observed extensively with HEGRA. For Mkn 421, spectral variations correlated with the flux level have been observed. The simultaneous observations at X-ray and TeV energies indicate a complex
Figure 3. The differential energy spectrum of H1426+428 from the 40 hrs of observations with HEGRA. On the right, the SED of the Optical/Infrared extragalactic background light is shown together with the extinction for TeV photons. The different curves are explained further in the text.

Figure 4. The combined TeV and X-ray light-curves in arbitrary units for the RXTE campaign on Mkn 421. The flux values have been normalized to the average value for each energy region.
light curve with only little correspondence of the flaring behaviour at the two
energies. The newly discovered source 1ES1959+650 has been detected at the
level of 5.4\sigma during a deep observation in 2000 and 2001. This source has
shown strong and unprecedented flares in 2002 accompanied by indications for
a flattening of the observed energy spectrum similar to what has been observed
for Mkn 421. The most distant TeV source H1426+428 (z = 0.129) has been
detected and the observed energy spectrum is consistent with absorption features
cau sed by pair-production processes with the diffuse extragalactic background
light between 1 − 15\mu m.

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