HEGRA CT1 Spectrum and Light Curve of Mrk-421 during its 2001 flare

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Abstract:

In the first months of 2001 Mrk-421 exhibited high TeV activity at flux levels well above 1 Crab. We present here the energy spectrum, the hardness ratio evolution and the light curve obtained with the HEGRA standalone CT1 telescope

„The universe viewed in γ-rays“, Kashiwa, Japan, 25-28 September 2002

Introduction:

Mrk-421 and Mrk-501 are the closest (z~0.03) and more extensively studied BL Lacs at TeV energies[1].
During a particularly strong flare back in 1997, Mrk-501 showed an exponential cutoff in the energy spectrum at an energy around 6 TeV[2], consistent with absorption in the IR extragalactic background. In 2001 Mrk-421 went through a similar flaring episode lasting for several months. Here we try to ascertain if this source shows a spectral cutoff similar to that found for Mrk-501 and thus consistent with external absorption of the TeV radiation. We also attempt to find evidence for spectral variability with flux level, as expected in most theoretical models and reported by several instruments[3,4].
First results of the 2001 flare were already presented at [5] and agree with this analysis.

Instrument, data sample:

The standalone HEGRA IACT CT1[6] has a reflector area of 10 m^2 and a camera of 127 0.25° PMTs. It achieves an energy threshold of ~600 GeV and an energy resolution ranging from 30% to 20% at the highest energies.
Both moonless and moon observations with reduced high voltage were performed during 2001, up to 60° zenith angle. Table 1 reviews the Mrk-421 sample after quality cuts:

Tab. 1: Mrk-421 data sample

HV setting	Hours	Excess events	Significance
Nominal, no moon	262.7	13718	88.7
Nominal, moon	46.9	2398	30.6
Reduced 4%	23.0	1014	18.6

For a detailed description of the data analysis we refer the reader to [7,8,9].

Light curve:

Fig. 1 shows the daily-average fluxes above 1 TeV during 2001. The CT system fluxes[3] have been added for comparison (it must be noted that both time samples do not fully overlap). Fast variations are observed in a faster than one day basis.
Intraday variability has been studied and doubling times faster than 20 min have been observed (see for instance Fig.2).
An autocorrelation analysis showed no evidence for periodicity[5,7].
The CT1 fluxes have been compared with the publicly available RXTE/ASM X-ray fluxes and a strong correlation with a correlation factor ~0.7 have been found with no evidence for a longer than 1 day time lag (see [5,7] for details).

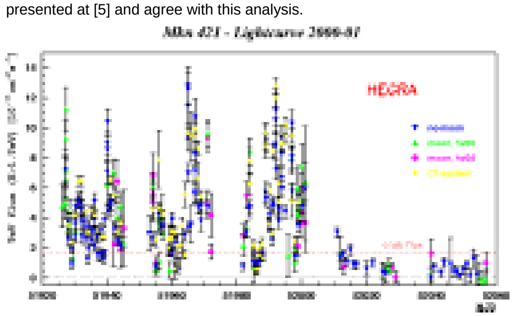

Fig.1: Diurnal flux light curve of Mrk-421 during 2001. The CT1 data have been taken under moon and moonless conditions. The CT system data light curve has been added for comparison. Flux doublings faster than one day are frequent. No obvious periodicity in noticeable (see also text).

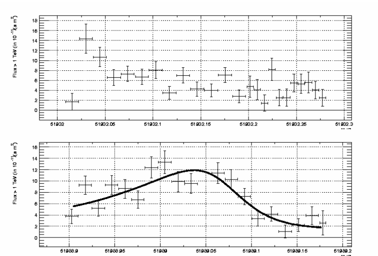

Fig.2: 20-min averaged flux light curve during MJD 51932 and MJD 51988. A doubling time faster than 20 min is observed for the first night.

Spectral variability:

The energy spectrum has been calculated for the moonless data sample (the moonshine spectrum is consistent with it but hardly adds any significance to the results). A power law is excluded with a probability of 10^{-18} (χ^2/ndf=68/9), while a power law with a cutoff is acceptable (χ^2/ndf=7.8/8):

dN/dE [cm^{-2} s^{-1}] =
$(6.8\pm0.4)\cdot10^{-11}\ E^{-1.96\pm0.17}\ e^{-E/(3.2\pm0.6\ \mathrm{TeV})}$

The total data sample has been split into five data sets at different flux levels (defined by limit fluxes in 10^{-11} cm^{-2} s^{-1}: 0.5-1, 1-2.5, 2.5-6, 6-10, 10-15). The corresponding spectra are shown in Fig. 3. A power law is excluded for all sets. An exponential cutoff is always acceptable. The cutoff energy does not significantly change with the total flux.
A fit with a fixed cutoff reveals a spectral index which hardens with total flux. The results of the fits can be found in Tab. 2.

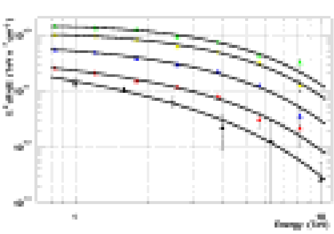

Fig.3: Energy spectra for data sets at different total flux levels. Data are fitted to a power law with an exponential cutoff.

A parabollic fit in log (E·dN/dE) vs log E is also acceptable for the full data sample (with χ^2/ndf=4.1/6). We have fixed the curvature of the parabollic fit to the value obtained for the full data sample and fitted the individual data sets. The position of the maximum is found to move to higher energies with total flux (note however that the fit is not statistically acceptable for low fluxes).

Set	Φ_0	α	E_{cut}	χ^2/ndf	Φ_0	α	χ^2/ndf
0.5-1	2.3±0.6	2.2±0.6	2.3±1.5	0.7/3	2.1±0.3	2.50±0.19	1.0/4
1-2.5	3.1±0.3	2.3±0.2	3.6±1.4	2.3/4	3.2±0.17	2.22±0.08	2.3/5
2.5-6	7.1±0.4	2.02±0.14	3.2±0.6	3.9/4	7.1±0.3	2.04±0.05	3.9/5
6-10	13.2±0.6	1.93±0.13	3.6±0.7	2.6/4	13.4±0.5	1.87±0.05	2.8/5
10-15	17.9±1.0	2.04±0.14	4.6±1.1	3.4/4	19.0±0.8	1.83±0.05	5.8/5

Tab.2: Results of spectral fits to $dN/dE = \Phi_0\ E^{-\alpha}\ e^{-E[\mathrm{TeV}]/E_{cut}}$ [cm^{-2} s^{-1}] with free cutoff (left) and E_{cut} fixed to 3.2 TeV (right).

Set	Φ_0	E_{peak}	χ^2/ndf
0.5-1	3.3±0.4	13±6	26/5
1-2.5	7.3±0.3	31±6	31/6
2.5-6	18.0±0.5	45±5	33/6
6-10	38.8±1.0	69±7	5.4/6
10-15	57.1±1.5	79±9	2.8/6

Tab.3: Results of spectral fits to a parabollic function in log (E·dN/dE) vs log E, with a fixed curvature. E_{peak} is the position of the maximum in GeV.

Further evidence for spectral variability is found when we plot the hardness ratio of the γ-ray flux in the 0.9-1.4 and 2.5-5.6 TeV energy intervals. The ratio is significantly correlated with the total flux above 1 TeV.

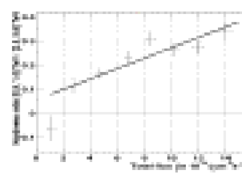

Fig.4: Hardness ratio of flux in the 0.9-1.4 TeV and 2.5-5.6 TeV energy intervals, versus total flux above 1 TeV.

Conclusions:

During the first months of 2001, the high energy BL Lac Mrk-421 went through a period of strong TeV emission. The CT1 light curve shows flares as short as a few minutes.
The energy spectrum shows a significant cutoff at an energy of 3.2±0.6 TeV. The sample has been divided in data sets according to total flux. No significant change in the cutoff energy are observed, as expected if the cutoff is due to IR absorption. The spectrum of the source is found to harden with total flux if one assumes a fixed energy cutoff.

References:

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