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Multiwavelength observations of PKS 2005-489 and H 2356-309 with HESS

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Abstract: Very-high-energy (VHE; >100 GeV) γ-ray observations of PKS 2005-489 and H 2356-309 were made with the High Energy Stereoscopic System (HESS) in 2005 and 2006. Previous 2004 data have been reanalysed to correct for the degradation of the optical efficiency of the HESS system. Both sources have been detected during all 3 years, at a level of 1-3% of the Crab flux. A total excess of $\sim$16σ and $\sim$12σ, respectively, is accumulated. Significant flux variations are seen on a monthly basis for H 2356-309, and in 2006 for PKS 2005-489. The spectra confirm the previously reported values, in particular the hard spectrum of H 2356-309. Multiwavelength observations performed with XMM and RXTE in 2004 and 2005 reveal remarkable flux (10x) and spectral ($\Delta\Gamma$=0.7) variations for PKS 2005-489. Despite a $\sim$10$\times$ flux increase above 1 keV, no flux variation is seen at VHE, implying in an SSC scenario a corresponding decrease of the energy density of the seed photons for inverse Compton (IC) scattering, not observed in the SED. A possible explanation is that a new component is emerging in the jet, whose electrons do not see the photons of the observed synchrotron peak. The SED of both objects shows the potential for significantly higher VHE fluxes.

Introduction

The blazars PKS 2005-489 (z=0.071) and H 2356-309 (z=0.165) are two high-frequency-peaked BL Lac objects (HBL). PKS 2005-489 is one of the brightest HBL in the southern hemisphere, and is characterized by very large variability in the X-ray band [1, 2]. H 2356-309 is an *extreme* BL Lac [3], characterized by the synchrotron peak of the spectral energy distribution (SED) at energies above a few keV. Both objects have been discovered by HESS as VHE sources in 2004 [4, 5], though at a rather faint flux ($\sim$2-3% Crab). Coordinated X-ray observations performed in the same epoch with XMM and RXTE revealed historically low fluxes, for both objects. Since in HBLs the X-ray band usually samples the synchrotron emission of TeV electrons, which produce VHE photons by inverse Compton (IC) scattering of low energy photons, significantly higher VHE fluxes can be expected. Monitoring observations in 2005 and 2006 were thus performed, both to increase the event statistics and to catch flaring events. Further multi-wavelength observations were also performed with XMM (as pre-planned pointings due to the narrow overlap between HESS and XMM visibility windows) and RXTE (as ToO). The main preliminary results on the average data are here reported.

HESS Results

All data have been analyzed with the HESS standard analysis [6, 7]. For the spectral and flux determination the energy of each event event is corrected [6] for the absolute optical efficiency of the system using efficiencies determined from simulated and observed muons. This correction eliminates any potential long-term variations in the absolute energy scale of the HESS analysis due to a changing optical throughput. The systematic error is $\sim$20% on flux and $\sim$0.1 for the photon index.

On PKS 2005-489, a total of 135.4 hours of observations were taken from 2004 through 2006. After data-quality selection, an exposure of 78.3 h livetime is obtained, at a mean zenith angle 36°. A point-like VHE γ-ray excess from PKS 2005-

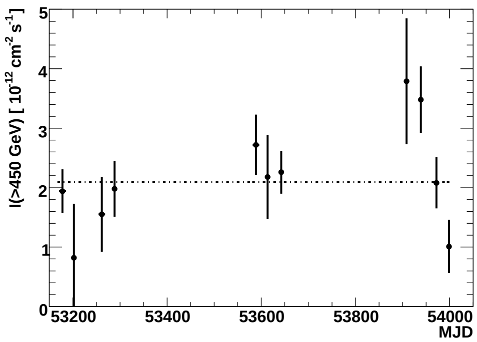

Figure 1: The integral flux (>450 GeV) measured by HESS from PKS 2005-489 in monthly bins. The 2004 values are ~3 times higher than previously published[4] as all fluxes are corrected[6] for degradation in the optical efficiency of the HESS system. Only the statistical errors are shown. The fluxes are calculated assuming the time-average spectrum measured in the respective year (Table 1). Simultaneous X-ray observations were performed on MJD 53282, 53608-53622 (RXTE) and 53641 (Table 2, respectively).

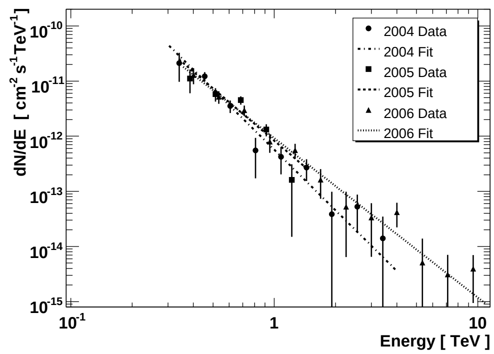

Figure 2: The annual VHE spectra observed from PKS 2005-489. The lines represent the best fit of a power-law model to the observed data, with photon index Γ reported in Table 1.

489 is detected each year, with an average flux of ~2.8% Crab. On a monthly basis (Fig. 1), there is indication of ~3× flux variability in 2006. At shorter timescales, no significant variability is detected, though comparable variations cannot be excluded. The annual VHE spectra measured are shown in Fig. 2 and Table 1. Among years, the flux below 1 TeV remains basically constant. There is only a slight (~1.8σ) indication of hardening between 2004 and 2006 spectra.

H 2356-309 has been observed by HESS for a total of 164 hours from 2004 through 2006. After data-quality selection, an exposure of 109.8 h is obtained, at mean zenith angle $19°$. Significant VHE emission is detected during each year, with clear indications of variability on an annual and monthly timescale (probability of constant flux <0.4%). At shorter timescales no significant variability is detected, though comparable variations cannot be excluded given the low statistics. Despite the variability, no significant spectral changes are observed (Table 1).

For the discussion of the SED properties of these two HBL, all the HESS spectra have been corrected for γ-γ absorption on the diffuse Extragalactic Background Light (EBL) with the P0.45 shape in [8] (close to the level from galaxy counts).

SED Changes in PKS 2005−489

Simultaneous X-ray observations were performed with XMM in Oct. 2004 and Sept. 2005, and with RXTE in Aug-Sept 2005. No significant variability is observed within each data set, on any timescale. From 2004 to 2005, the spectrum above 1 keV hardens strongly ($\Delta\Gamma$=0.7), yielding a ~10× flux increase. The UV fluxes (close to the synchrotron peak) show a ~30% increase as well. In contrast,

Table 1: Results of the HESS observations. Shown are the epoch, exposure time, significance of the excess, integral flux (in units of 10^{-13} cm^{-2} s^{-1}) and photon index for a single power-law fit. Only the statistical errors are shown.

Epoch	Time [h]	Sign. [σ]	Int. Flux [f.u.]	Γ
PKS 2005-489			(>450 GeV)	
2004	24.2	7.7	1.81±0.26	3.65±0.39
2005	32.6	11.0	2.38±0.27	3.15±0.30
2006	21.5	8.8	2.20±0.26	2.89±0.20
Total	78.3	15.9	2.08±0.15	3.18±0.16
H 2356-309			(>200 GeV)	
2004	39.9	9.6	5.97±0.61	2.97±0.19
2005	46.7	5.9	3.28±0.65	2.99±0.39
2006	23.2	5.1	3.49±0.82	3.43±0.41
Total	109.8	12.1	4.47±0.39	3.09±0.16

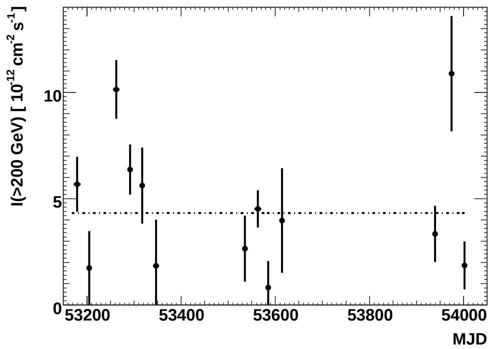

Figure 3: The integral flux (>200 GeV) measured by HESS from H 2356-309, in monthly bins. All fluxes are corrected for the degradation of the HESS optical efficiency [6]. Statistical errors only. The fluxes are calculated assuming the time-average spectrum measured in the respective year (Table 1). There is clear indication of variability (probability of constant flux <0.4%). Simultaneous X-ray observations were performed on MJD 53320 (RXTE), 53534 and 53536 (Table 2, respectively).

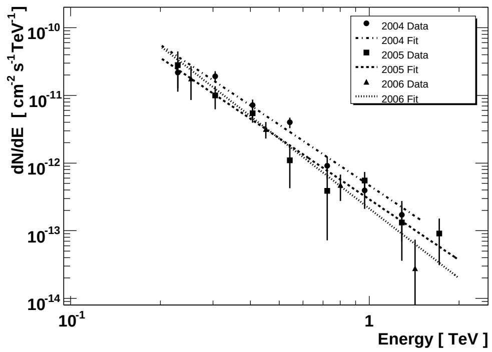

Figure 4: The annual VHE spectra observed from H 2356-309. The lines represent the best fit of a power-law model to the observed data, with photon index Γ reported in Table 2. No significant spectral variation is observed. An analysis of combined data for different flux levels is on-going.

the VHE emission remains almost constant, with a spectrum that suggests it can be produced by the same electrons emitting by synchrotron in the hard X-ray band. However, the VHE flux should have increased at least linearly with the X-ray flux between the two epochs, if these electrons could upscatter by IC the observed synchrotron peak photons. For the VHE flux to remain constant, a corresponding decrease of the seed-photons energy density is required. This suggests that a new jet component is emerging, physically separated from the main emitting blob, and whose synchrotron peak emission remains at present hidden below the observed SED.

Table 2: Best-fit parameters of the X-ray data. Single and broken power-law models (XMM: MOS+PN data). Column density N_H fixed to galactic values, and modelled with Tbabs using Wilms abundances. The errors are quoted at the 90% confidence level. Unabsorbed flux in units of erg cm^{-2} s^{-1} in the 2-10 KeV band.

Instr.	Γ_1	E_{br} [keV]	Γ_2	Flux [f.u.]
PKS 2005-489				
XMM	-	-	3.04±0.05	1.2E-12
RXTE	-	-	2.9±0.2	7.6E-12
XMM	3.0±0.1	0.5	2.27±0.03	2.0E-11
H 2356-309				
RXTE	-	-	2.43±0.25	9.7E-12
XMM	2.00±0.05	1.0	2.34±0.03	7.2E-12
XMM	1.92±0.06	0.9	2.23±0.03	8.7E-12

SED Changes in H 2356−309

The X-ray flux and spectral properties appear to be almost constant among these trhee epochs, at a flux level ~3× lower than the *Beppo*SAX values (June 1998[3]). The XMM spectra confirm the location of the synchrotron peak in the X-ray band (at 1-2 KeV), as derived from the *Beppo*SAX data. The hard VHE spectra, now measured with better statistics, confirm the constraints on the EBL previously obtained from the 2004 dataset[8]. Once corrected for intergalactic $\gamma-\gamma$ absorption, the hard VHE spectrum locates the IC peak of the SED above 1 TeV.

Conclusion

Observations performed by HESS from 2004 through 2006 have confirmed PKS 2005-489 and H 2356-309 as VHE gamma-ray sources, at an average annual level of 1-3% Crab. The VHE spectra confirm the very different SED properties of these two HBL, with very soft and hard intrinsic

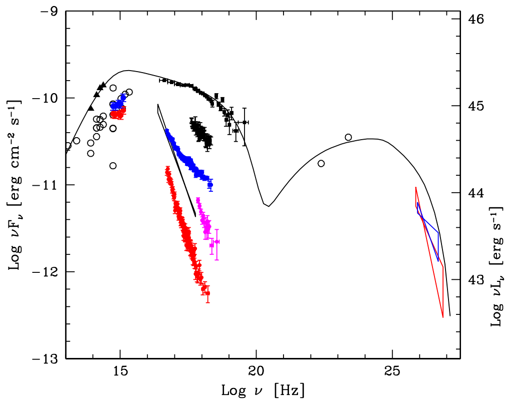

Figure 5: SED of PKS 2005-489. Black: historical data and modelling of the strong 1998 flare [2]. Corrected for EBL absorption (P0.45 curve in [8]), the intrinsic VHE slopes obtained are Γ_{int}=3.1 $\pm$ 0.4 (red, year 2004) and Γ_{int}=2.6 $\pm$ 0.3 (blue, year 2005). The Opt-UV fluxes from the Optical Monitor (OM) onboard XMM are corrected for galactic extinction using the Cardelli et al. (1998) curve. XMM data processed with SAS7.0. The hard (Γ <2) UV spectrum indicated by the OM photometry locates the synchrotron peak between the Far-UV and Soft X-ray range.

spectra respectively. Simultaneous observations with RXTE and XMM have confirmed the correlation between SED peak energies, with the higher synchrotron peak frequency observed in the object with the higher IC peak energy. X-ray observations have also shown the objects to be in historically low states. For PKS 2005-489, the overall SED evolution suggests that a new jet component is emerging, with harder properties. Since PKS 2005-489 has historically demonstrated a 100$\times$ dynamical range in the X-ray band, dramatically higher VHE fluxes ($10^2 - 10^4\times$) can be expected in a leptonic scenario, unless counterbalanced by a strong (>10$\times$) and simultaneous increase of the magnetic field. These results confirm the strong diagnostic potential of coordinated Optical–X-ray–VHE observations. Further monitoring of these objects is highly encouraged.

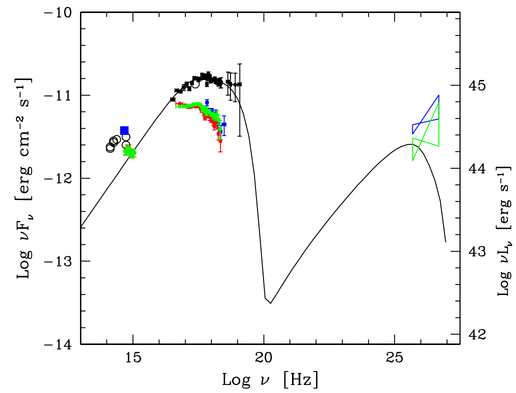

Figure 6: SED of H 2356−309. Black: historical data and modelling[3]. After correction for EBL absorption, the intrinsic VHE slopes are Γ_{int}=1.7$\pm$0.2 (blue, year 2004) and Γ_{int}=1.7$\pm$0.4 (green, year 2005). Blue symbols: data discussed in [5]. Optical fluxes from ROTSE and XMM-OM .

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