Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 3 (OG part 2), pages 1065–1068

30TH INTERNATIONAL COSMIC RAY CONFERENCE

Upper Limits from HESS Observations of AGN in 2005-2007

W. BENBOW[1] AND R. BÜHLER[1] FOR THE HESS COLLABORATION
[1] *Max-Planck-Institut für Kernphysik, Heidelberg, Germany*
Wystan.Benbow@mpi-hd.mpg.de

Abstract: Very high energy (VHE; >100 GeV) observations of a sample of selected active galactic nuclei (AGN) were performed between January 2005 and April 2007 with the High Energy Stereoscopic System (HESS), an array of imaging atmospheric-Cherenkov telescopes. Significant detections are reported elsewhere for many of these objects. Here, integral flux upper limits for twelve candidate very-high-energy (VHE; >100 GeV) gamma-ray emitters are presented. In addition, results from HESS observations of four known VHE-bright AGN are given although no significant signal is measured. For three of these AGN (1ES 1101−232, 1ES 1218+304, and Mkn 501) simultaneous data were taken with the Suzaku X-ray satellite.

Introduction

The HESS array [1] of four imaging atmospheric-Cherenkov telescopes located in Namibia is used to search for VHE γ-ray emission from various classes of astrophysical objects. Approximately 300 hours per year, $\sim$30% of the total observation budget, are dedicated to HESS studies of AGN. These observations are divided between monitoring the flux of known VHE-bright AGN and searching for new VHE sources. For the monitoring observations, an AGN is typically observed for a few hours, distributed over several nights, a month for $\sim$3 months, with the hopes of detecting a bright flaring episode (see, e.g., [2]). In the discovery part of the AGN program, a candidate from a large, diverse sample of relatively nearby AGN is typically observed for $\sim$10 hours. If any of these observations show an indication for a signal (e.g., an excess with significance more than $\sim$3 standard deviations), a deeper exposure is promptly scheduled to increase the overall significance of the detection and to allow for a spectral measurement.

The targets of HESS AGN observations are primarily blazars, a class which includes both BL Lac objects and Flat Spectrum Radio Quasars (FSRQ). The spectral energy distributions (SEDs) of these objects are generally characterized by two peaks: a lower-energy one in the optical to X-ray regime, and another which potentially extends to γ-ray energies. Based on their SEDs, BL Lacs are generally categorized into groups that are either low (LBL), intermediate (IBL), or high-frequency-peaked (HBL). An overwhelming majority of VHE-emitting AGN are HBL, therefore these objects are the primary targets of HESS AGN observation program. However, prominent examples of different types of AGN are also observed with the hopes of detecting new AGN classes. These include radio-loud objects such as Fanaroff-Riley (FR) galaxies and narrow line Seyfert (NLS) galaxies, and radio-weak objects like typical Seyfert (Sy) galaxies, all of which come in several types (generally I or II).

For all the following results, the HESS standard analysis [3] is used. All upper limits are given at the 99% confidence level [4]. The flux quantities are calculated assuming a power-law spectrum with photon index Γ=3.0, with the exception of those for 1ES 1101−232 where Γ=2.94, as measured [5] in 2004-05, is chosen. The reported values change by less than $\sim$10% when a different photon index (i.e. Γ between 2.5 and 3.5) is assumed. The effects of changes in the absolute optical efficiency of HESS are corrected for using efficiencies determined from simulated and observed muons [6]. The systematic error on all flux quantities is estimated to be $\sim$20%.

Table 1: The candidate AGN in groups of blazars and non-blazars. The asterisk denotes the four candidates detected by the EGRET satellite [7]. The redshift (z), total good-quality live time (T), mean zenith angle of observation ($Z_{\rm obs}$), the observed excess and significance (S) are shown. Integral flux upper limits above the energy threshold of the observations ($E_{\rm th}$), and the corresponding percentage of the HESS Crab Nebula flux [6] above the same threshold, are also shown. The flux units are 10^{-12} cm^{-2} s^{-1}. The † represents the six upper limits which are the most constraining ever reported for the object.

Object	z	Type	T [hrs]	$Z_{\rm obs}$ [°]	Excess	S [σ]	$E_{\rm th}$ [GeV]	I(>$E_{\rm th}$) [f.u.]	Crab %
Blazar									
III Zw 2	0.0893	FSRQ	1.7	37	12	1.4	420	5.36†	6.4
BWE 0210+116*	0.250	LBL	6.0	43	−13	−0.9	530	0.72†	1.2
1ES 0323+022	0.147	HBL	7.2	27	13	0.7	300	2.52	1.9
PKS 0521−365*	0.0553	LBL	3.1	26	11	0.8	310	5.40†	4.2
3C 279*	0.536	FSRQ	2.0	26	5	0.5	300	3.98†	2.9
RBS 1888	0.226	HBL	2.4	15	30	2.2	240	9.26	4.9
PKS 2316−423	0.055	IBL	4.1	20	29	1.6	270	4.74	3.0
1ES 2343−151	0.226	IBL	8.6	17	−16	−0.6	230	2.45†	1.2
Non-blazar									
NGC 1068	0.00379	Sy II	1.8	29	9	1.1	330	5.76	4.9
Pictor A	0.0342	FR II	7.9	31	−23	−1.1	320	2.45	2.0
PKS 0558−504	0.137	NLS I	8.3	28	−14	−0.7	310	2.38†	1.8
NGC 7469	0.0164	Sy I	3.4	34	−14	−1.3	330	1.38	1.2

Limits from Discovery Observations

Twenty-nine AGN were observed by HESS from January 2005 through April 2007. Some of these objects were previously shown by HESS to emit VHE γ-rays, and the discoveries of VHE emission from others are reported elsewhere. Of the remaining AGN with non-zero good-quality exposure, twelve show no indication of any VHE emission. As many of the HBL observed by HESS have been detected, the twelve candidates discussed in this section are largely not HBL. Table 1 shows these AGN, their redshift and AGN type, as well as details of their observations. The mean good-quality exposure for the candidates is 4.7 hours live time at a mean zenith angle of 28°. In 5 hours of observations, the sensitivity of HESS [3] enables a 5σ detection of an ∼2% Crab Nebula flux source at 20° zenith angle.

As mentioned previously, no significant excess of VHE γ-rays is found from any of these twelve AGN in the given exposure time. Figure 1 shows the distribution of the significance observed from the direction of each AGN. The measured excess, corresponding significance and resulting integral flux limits are given in Table 1 for each AGN. Six of the upper limits are the most constraining ever reported from these objects, and the other six limits are only surpassed by those from HESS observations in 2004 [8]. Combining the excess from all twelve candidates only yields a total of 29 events and a statistical significance of 1.1σ. No significant excess is found in a search for serendipitous source discoveries in the HESS field-of-view centered on each of the AGN. Further, as the nightly flux from each target is well-fit by a constant, no evidence for VHE flares is found from any of the twelve AGN.

Low Altitude HESS Observations

Three northern AGN, known to emit VHE γ-rays, were briefly (good-quality live time <2.2 h) observed at low altitudes with HESS. At such al-

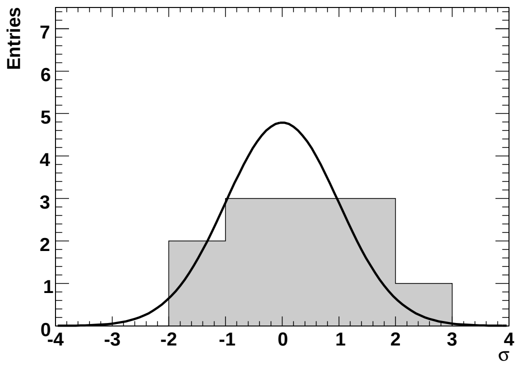

Figure 1: Distribution of the significance observed from the twelve candidate AGN. The curve represents a Gaussian distribution with zero mean and a standard deviation of one.

titudes the threshold of HESS is higher and the sensitivity is reduced. However, observations at low altitudes sample the VHE spectrum at much higher energies than the typical near-zenith observations made with Cherenkov-telescope arrays. Simultaneous measurements of the same northern target with HESS and a Northen Hemisphere instrument enable both the determination of the object's spectrum over several orders of magnitude in energy, as well as cross-calibration between the instruments (see, e.g., [9]). For two of these targets (1ES 1218+304 and Mkn 501) simultaneous observations were successfully performed by the MAGIC VHE telescope and the Suzaku X-ray satellite [10].

HESS observed Mkn 421 on April 12, 2005. The good-quality exposure is 0.9 h live time at a mean zenith angle of $63°$. A marginally significant excess (28 events, 3.5σ) is found. The corresponding integral flux above the 2.1 TeV analysis threshold is I(>2.1 TeV) = $(3.1\pm1.0_{\rm stat})\times10^{-12}$ cm^{-2} s^{-1}, or 45% of the HESS Crab Nebula flux above the same threshold.

The HESS observations of 1ES 1218+304 on May 19, 2006 yield a good-quality data set of 1.8 h live time at a mean zenith angle of $56°$. The resulting excess is not significant (9 events, 1.2σ). The upper limit on the integral flux above the 1.0 TeV analysis threshold is I(>1.0 TeV) $<$ 3.9×10^{-12} cm^{-2} s^{-1}. This corresponds to 17% of the HESS Crab Nebula flux above the same threshold.

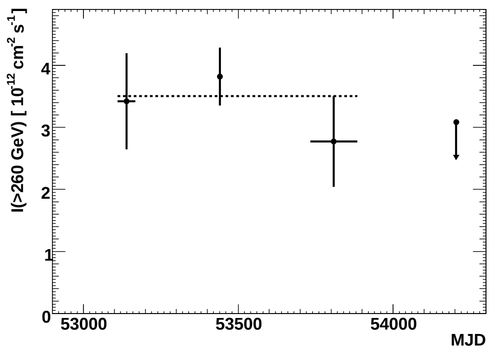

Figure 2: The annual light curve, I(>260 GeV), from HESS measurements of 1ES 1101$-$232. The upper limit in 2007 is at the 99.9% confidence level. The 2004 and 2005 data are published elsewhere [5]. The actual observation dates are shown by the x-error bars. The dashed line is the average flux measured from 2004-2006.

HESS observations of Mkn 501 occurred on July 18, 2006. All data pass the standard quality-selection criteria, yielding an exposure of 2.2 h live time at a mean zenith angle of $64°$. Mkn 501 is not detected by HESS as the resulting excess is -9 events (-0.8σ). The upper limit on the integral flux above the 2.5 TeV analysis threshold is I(>2.5 TeV) $<$ 1.1×10^{-12} cm^{-2} s^{-1}, or 22% of the HESS Crab Nebula flux above the same threshold.

VHE Monitoring of 1ES 1101$-$232

1ES 1101$-$232 was discovered by HESS [11, 5] to emit VHE γ-rays during observations in 2004-2005. As part of a campaign to monitor its VHE flux, it was re-observed for a total (good-quality observations) of 18.3 h in 2006-07. A marginally significant excess (117 events, 3.6σ) is detected from 1ES 1101$-$232 in the 2006 observations (13.7 h), and the object is not detected (16 events, 0.9σ) in 2007. As can be seen from Figure 2 the upper limit from 2007 falls below the average flux measured by HESS from 2004-2006. Some of the 2006 HESS data (4.3 h) are simultaneous with Suzaku X-ray observations. In these data, the blazar is again marginally detected (51 events, 0.9σ) and the corresponding flux is I(>260 GeV) $< (3.2 \pm 1.4_{\rm stat}) \times 10^{-12}$ cm^{-2} s^{-1}.

Discussion & Conclusions

One of the defining characteristics of AGN is their extreme variability. The VHE flux from any of these AGN may increase significantly during future flaring episodes (see, e.g., [2]) and could potentially exceed the limits presented here. In addition, accurate modeling of the SED requires that the state of the source is accounted for. Therefore, in the absence of contemporaneous observations at lower energies, it is recommended that these results be conservatively interpreted as limits on, or measurements of, the steady-component or quiescent flux from the AGN. Clearly, the simultaneous Suzaku X-ray data from Mkn 501, 1ES 1218+304, and 1ES 1101−232, make the HESS results from these objects particularly useful. Finally, interpretation of the SED of an AGN not only requires accounting for the state of the source, but also the redshift and energy dependent absorption [12] of VHE photons on the Extragalactic Background Light (EBL), which is potentially large [11, 13] for some of these sources.

With the detection of ten VHE AGN, including the discovery of seven, the HESS AGN observation program has been highly successful. However, despite more than five years of operations, the observation program is not complete as many proposed candidates have either not yet been observed or only have a fraction of their intended exposure. Therefore, the prospects of finding additional VHE-bright AGN with HESS are still excellent.

Acknowledgements

The support of the Namibian authorities and of the University of Namibia in facilitating the construction and operation of H.E.S.S. is gratefully acknowledged, as is the support by the German Ministry for Education and Research (BMBF), the Max Planck Society, the French Ministry for Research, the CNRS-IN2P3 and the Astroparticle Interdisciplinary Programme of the CNRS, the U.K. Science and Technology Facilities Council (STFC), the IPNP of the Charles University, the Polish Ministry of Science and Higher Education, the South African Department of Science and Technology and National Research Foundation, and by the University of Namibia. We appreciate the excellent work of the technical support staff in Berlin, Durham, Hamburg, Heidelberg, Palaiseau, Paris, Saclay, and in Namibia in the construction and operation of the equipment.

References

[1] Hinton, J. 2004, New Astron Rev, 48, 331
[2] Aharonian, F., et al. (HESS Collaboration) 2007, ApJ, in press [arXiv:astro-ph/0706.0797]
[3] Benbow, W. 2005, Proceedings of Towards a Network of Atmospheric Cherenkov Detectors VII (Palaiseau), 163
[4] Feldman, G.J. & Cousins, R.D. 1998, Phys Rev D, 57, 3873
[5] Aharonian, F., et al. (HESS Collaboration) 2007, A&A, 470, 475
[6] Aharonian, F., et al. (HESS Collaboration) 2006, A&A, 457, 899
[7] Hartman, R.C., et al. 1999, ApJS, 123, 79
[8] Aharonian, F., et al. (HESS Collaboration) 2005, A&A, 441, 467
[9] Mazin, D., et al. 2005, Proceedings of the 29th ICRC (Pune), 4, 331
[10] Mitsuda, K., et al. 2007, PASJ, 59, 1
[11] Aharonian, F., et al. (HESS Collaboration) 2006, Nature, 440, 1018
[12] Gould, R.J., & Schréder, G.P. 1967, Phys Rev, 155, 1408
[13] Hauser, M.G. & Dwek, E. 2001, ARA&A, 39, 249