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Observations of Selected AGN with H.E.S.S.

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A sample of selected active galactic nuclei (AGN) was observed in 2003 and 2004 with the High Energy Stereoscopic System (H.E.S.S.), an array of imaging atmospheric-Cherenkov telescopes in Namibia. The redshifts of these candidate very-high-energy (VHE, >100 GeV) γ-ray emitters range from z=0.00183 to z=0.333. Significant detections were already reported for some of these objects, such as PKS 2155−304 and Mkn 421. Marginal evidence (3.1σ) for a signal is found from large-zenith-angle observations of Mkn 501, corresponding to an integral flux of I(>1.65 TeV) = $(1.5\pm0.6_{\rm stat}\pm0.3_{\rm syst}) \times 10^{-12}$ cm^{-2} s^{-1} or ∼15% of the Crab Nebula flux. Integral flux upper limits for 19 other AGN, based on exposures of ∼1 to ∼8 hours live time, and with average energy thresholds between 160 GeV and 610 GeV, range from 0.4% to 5.1% of the Crab Nebula flux. All the upper limits are the most constraining ever reported for these objects.

1. Introduction

The H.E.S.S. experiment, an array of four imaging atmospheric-Cherenkov telescopes located in Namibia, uses stereoscopic observations of γ-ray induced air showers to search for astrophysical γ-ray emission at VHE energies. Each telescope has a 107 m^2 tessellated mirror dish and a 5° field-of-view (f.o.v.) camera consisting of 960 individual photomultiplier pixels. The sensitivity of H.E.S.S. (5σ in 25 hours for a 1% Crab Nebula flux source at 20° zenith angle) allows for detection of VHE emission from objects, such as AGN, at previously undetectable flux levels. More details on H.E.S.S. can be found in [8], [12], [13], and [18].

To help constrain the models for production of VHE γ-rays by AGN, and to explore the VHE photon absorption by the extragalactic background light (EBL) [15], a large sample of AGN located at z<0.333 was observed by H.E.S.S. in 2003 and 2004. Most of these objects are BL Lacs, since essentially all AGN detected so far at VHE energies are radio-loud objects of the BL Lac type. Many of these BL Lacs are suggested as good candidates for detection as VHE emitters [10, 16]. Given the VHE detection [1, 7] of the Fanaroff-Riley type I radio galaxy M 87, a sample of nearby non-blazar AGN was also observed with the hope of extending the known VHE-bright AGN to other classes. These include a set of famous radio-loud galaxies, characterized by resolved radio, optical and X-ray jets (Cen A, Pictor A, 3C 120, and the quasar 3C 273) and a sample of radio-weak objects (the Seyfert galaxies NGC 1068, NGC 3783 and NGC 7469). The detections resulting from the H.E.S.S. AGN observation program have been reported elsewhere. These include the detection of VHE γ-rays from the known VHE emitters M 87 [7], PKS 2155−304 [3], and Mkn 421 [5], as well as the discovery of VHE emission from PKS 2005−489 [4], H 2356−309 [17], and 1ES 1101-232 [14]. Flux upper limits, the strongest ever produced, from the non-detection of the remaining objects [6] are presented here.

2. H.E.S.S. Observations & Results

Table 2 shows the candidate AGN observed by H.E.S.S. and gives details of the observations that pass selection criteria which remove data for which the weather conditions were poor or the hardware was not functioning properly. The data were taken in 28 minute runs using *Wobble* mode, i.e. the source direction is offset, typically by ±0.5°, relative to the center of the f.o.v. of the camera during observations, which allows for both on-source observations and simultaneous estimation of the background induced by charged cosmic rays. Any data passing the run selection criteria are calibrated as detailed in [2], and analyzed using techniques described in [6].

Table 1. The candidate AGN ordered by right ascension in groups of BL Lacs, other radio-loud galaxies and radio-weak galaxies. The coordinates (J2000) and type (BL=BL Lacs, FSRQ=Flat Spectrum Radio Quasar, Sy=Seyferts (types I & II), FR=Fanaroff-Rileys (types I & II)) are shown. Any observations where some data do not use the full four-telescope array are marked by an $*$ in the live time (T) column. The mean zenith angle of observation (Z_{obs}), the corresponding post-selection cuts energy threshold (E_{th}), the observed excess and significance are also shown.

Object	α [hh mm ss]	δ [dd mm ss]	Type	T [hours]	Z_{obs} [°]	E_{th} [GeV]	Excess	S [σ]
BL Lacs								
1ES 0145+138	01 48 29.8	+14 02 19	BL	4.3*	40	310	1.2	0.1
1ES 0229+200	02 32 48.6	+20 17 17	BL	0.8	46	410	−1.4	−0.3
1ES 0323+022	03 26 14.0	+02 25 15	BL	4.7*	29	210	7.2	0.4
PKS 0548−322	05 50 40.6	−32 16 16	BL	4.1	20	190	39.0	2.1
EXO 0556.4−3838	05 58 06.2	−38 38 27	BL	1.2	33	250	17.2	1.7
RGB J0812+026	08 12 01.9	+02 37 33	BL	0.7*	30	220	−2.7	−0.4
RGB J1117+202	11 17 06.2	+20 14 07	BL	3.8*	52	610	1.9	0.1
1ES 1440+122	14 42 48.3	+12 00 40	BL	0.9	38	290	2.3	0.3
Mkn 501	16 53 52.2	+39 45 37	BL	1.8	64	1650	28.1	3.1
RBS 1888	22 43 42.0	−12 31 06	BL	2.6	15	170	−18.7	−1.3
Q J22548−2725	22 54 53.2	−27 25 09	BL	2.1	13	170	−6.1	−0.4
PKS 2316−423	23 19 05.9	−42 06 49	BL	2.2	21	190	−12.9	−0.9
1ES 2343−151	23 45 37.8	−14 49 10	BL	2.6*	11	160	−2.8	−0.2
Radio-Loud Galaxies								
3C 120	04 33 11.1	+05 21 16	FR I	5.0	32	230	−42.7	−2.5
Pictor A	05 19 49.7	−45 46 45	FR II	7.4	27	220	23.2	1.0
3C 273	12 29 06.7	+02 03 09	FSRQ	3.9	37	280	8.5	0.5
Cen A	13 25 27.6	−43 01 09	FR I	4.2	21	190	8.5	0.4
Radio-Weak Galaxies								
NGC 1068	02 42 40.8	−00 00 48	Sy II	4.3	27	210	12.6	0.8
NGC 3783	11 39 01.8	−37 44 19	Sy I	1.8*	27	220	−1.8	−0.2
NGC 7469	23 03 15.8	+08 52 26	Sy I	4.3	33	250	−31.2	−1.8

Figure 1 shows the distribution of the significance observed from the direction of each of the twenty AGN. No significant excess of VHE γ-rays is found from any of the AGN in the given exposure time (<8 hours each), with the possible exception of Mkn 501 (3.1σ). Specific details of the results for each AGN are shown in Table 2. Additionally, a search for serendipitous source discoveries in the H.E.S.S. f.o.v. centered on each of the AGN yielded no significant excess.

Given that it is well established that Mkn 501 is a VHE γ-ray emitter, the excess (3.1σ) from the only night (MJD 53172) of observations of Mkn 501 can be treated as significant and a flux calculated. Assuming the spectrum measured above 1.5 TeV by HEGRA [9], a power law with a photon index of Γ=2.6, the corresponding integral flux above the 1.65 TeV energy threshold is I(>1.65 TeV) = $(1.5\pm0.6_{stat}\pm0.3_{syst}) \times 10^{-12}$ cm^{-2} s^{-1} or $\sim$15% of the H.E.S.S. Crab Nebula flux above this threshold. While the VHE flux from Mkn 501 is known to be highly variable, the measured flux is similar to the value reported in [9].

For the remaining undetected AGN, 99.9% upper limits on the integral flux (assuming a power law spectrum with Γ=3.0) above the energy threshold of the observations are shown in Table 2. Assuming a different photon

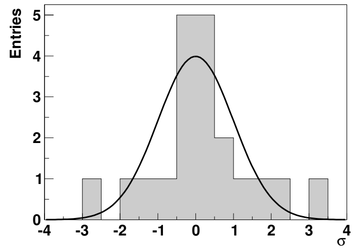

Figure 1. Distribution of the significance observed from the 20 selected AGN. The curve represents a Gaussian distribution with zero mean and a standard deviation of one.

Table 2. Integral flux upper limits (99.9% confidence level, method of [11], units are 10^{-12} cm^{-2} s^{-1}) above the energy threshold of observations (E_{th}) and the corresponding percentage of the H.E.S.S. Crab Nebula flux from observations (dates also given) of each of the candidate AGN (redshifts also given) by H.E.S.S..

Object	MJD−50000	z	E_{th} [GeV]	I(>E_{th})	Crab %
BL Lacs					
1ES 0145+138	3202,3205,3210-14	0.125	310	2.11	1.5
1ES 0229+200	3317	0.140	410	2.76	3.1
1ES 0323+022	2904-05,3267	0.147	210	3.92	1.5
PKS 0548−322	3296,3299-300,3303	0.069	190	6.65	2.2
EXO 0556.4−3838	3347,3354	0.034	250	10.1	5.1
RGB J0812+026	3081	—	220	7.49	3.1
RGB J1117+202	3054,3112,3114,3116	0.139	610	1.44	3.0
1ES 1440+122	3110,3119	0.162	290	5.11	3.3
RBS 1888	3207-08,3210	0.226	170	3.19	0.9
Q J22548−2725	3201,3210-11	0.333	170	5.83	1.6
PKS 2316−423	3201,3207-08	0.055	190	4.13	1.4
1ES 2343−151	3211-13	0.226	160	6.43	1.6
Radio-Loud Galaxies					
3C 120	3316-19,3353-55	0.033	230	0.92	0.4
Pictor A	3269,3318-19,3351,3353-54	0.034	220	3.33	1.4
3C 273	3109-10,3148-49	0.158	280	2.90	1.8
Cen A	3111-13	0.00183	190	5.68	1.9
Radio-Weak Galaxies					
NGC 1068	3290,3292-94,3296	0.00379	210	3.28	1.3
NGC 3783	3107-08	0.00965	220	6.04	2.5
NGC 7469	3202,3206,3211-12	0.016	250	1.27	0.6

index (i.e. Γ between 2.5 and 3.5) has less than a ∼10% effect on the reported limits, and the systematic error on the upper limits is estimated to be ∼20%. The H.E.S.S. limits are considerably (>5 times) stronger than any reported to date. However, due to the generally variable nature of AGN emission, these upper limits constrain the maximum average brightness of the AGN only during the observation time. Hence they are limits only on the steady-component or quiescent flux from the AGN. Future flaring behavior may increase the VHE flux from any of these AGN to significantly higher levels.

A search for VHE flux variability from each observed AGN was also performed. Here the nightly integral flux above the average energy threshold was calculated assuming a photon index of Γ=3.0 and fit by a constant. Any flaring behavior would be demonstrated in the form of a poor χ^2 probability for the fit. No evidence for VHE flux variability is found (P(χ^2) > 0.13 for each AGN). The lack of any significant VHE detection or flaring behavior is perhaps expected as none of the individual AGN (for which RXTE/ASM data exists) were particularly active in X-rays during the dates of the H.E.S.S. observations.

3. Conclusions

H.E.S.S. observed greater than twenty AGN in 2003 and 2004 as part of a campaign to identify new VHE-bright AGN. Several significant detections from this campaign have been reported elsewhere ([7], [5], [3], [4], [14], [17]). Results presented here (more details and discussion published in [6]) describe the AGN observations for which no significant excess was found, apart from a marginal signal from the well-known VHE-emitter Mkn 501. Despite the limited exposure (<8 hours, 3.2 hours on average) for each of these AGN, the upper limits on the VHE flux determined by H.E.S.S. are the most stringent to date, demonstrating the unprecedented sensitivity of the instrument. Clearly the strength of the limits makes them quite useful. Indeed many of the limits fall below published VHE flux predictions ([16], [10]). However, it must be stressed that any interpretation using the H.E.S.S. limits must take into account both the EBL and the state of the source using simultaneous data at different wavelengths.

The H.E.S.S. AGN observation program is not complete as many proposed candidates have not yet been observed. Further, more time is scheduled for observations of some of the AGN presented here as part of a monitoring effort. H.E.S.S. has already detected γ-ray emission from six AGN, including three never previously detected in the VHE regime. Clearly the prospects of finding additional VHE-bright AGN are excellent.

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