Upper Limits from H.E.S.S. AGN Observations in 2005-2007

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Abstract

A sample of active galactic nuclei (AGN) was observed between January 2005 and June 2007 with the High Energy Stereoscopic System (H.E.S.S.), an array of imaging atmospheric-Cherenkov telescopes. Significant detections are reported elsewhere for many of these objects. Results from the remaining H.E.S.S. observations are reported here. Integral flux upper limits for 12 AGN, based on exposures of ~2 to ~9 hours live time, and with average energy thresholds between 230 GeV and 530 GeV, range from 1.2% to 6.4% of the Crab Nebula flux. Many of the upper limits are the most constraining ever reported for these objects. In addition, results from H.E.S.S. observations of four known VHE-bright AGN (Mkn 421, Mkn 501, 1ES1218+304, and 1ES 1101-232) are given although no significant signal is measured. During observations of the latter three objects simultaneous data were taken with the Suzaku X-ray satellite.

Introduction

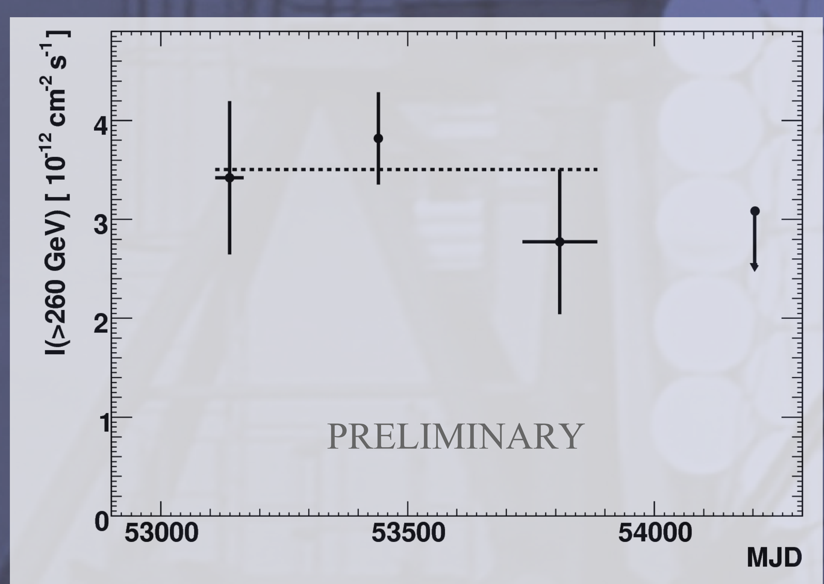
The H.E.S.S. experiment, an array of four imaging atmospheric-Cherenkov telescopes located in Namibia, uses stereoscopic observations of γ-ray induced air showers to search for astrophysical γ-ray emission at VHE energies. Each telescope has a 107 m^2 tessellated mirror dish and a 5° field-of-view (f.o.v.) 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) has enabled the detection of VHE emission from 10 AGN.

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), a large sample of AGN located at z<0.536 was observed by H.E.S.S. Most of these objects are blazars, particularly high-frequency peaked BL Lacs (HBL), similar to essentially all AGN detected so far at VHE energies. Many of these HBL are suggested as good candidates for detection as VHE emitters [7,9]. Other blazar targets include intermediate-frequency peaked BL Lacs (IBL), a high-frequency peaked Flat Spectrum Radio Quasar (HFSRQ), and EGRET-detected AGN. 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 radio-loud galaxy with resolved jets at lower energies (Pictor A) and some radio-weak Seyfert galaxies.

VHE Monitoring of 1ES 1101-232

1ES 1101-232 was discovered [2,4] by H.E.S.S. to emit VHE γ-rays during observations in 2004-2005. It was re-observed in "2006" (Dec. 29, 2005 to May 28, 2006) and 2007 (Apr. 9-17) to monitor for potential VHE flaring behavior. A total of 18.3 hours of good-quality observations were performed. The Suzaku X-ray satellite continuously observed 1ES 1101-232 from 16:07 UTC on May 25, 2006 until 05:11 UTC on May 27, 2006. A total of 4.3 hours of good-quality HESS data are simultaneous to the Suzaku observations. A marginal excess is detected during the Suzaku observations and in the "2006" data. The object is not detected in 2007. Results from all epochs are shown below.

Epoch	T [h]	Excess	Signif. [σ]	I(>260 GeV) [10^{-12} cm^{-2} s^{-1}]
2006	13.7	117	3.6	$2.8\pm0.7_{stat}$
2007	4.6	16	0.9	<3.1
Total	18.3	133	3.6	$2.0\pm0.6_{stat}$
Suzaku	4.3	51	2.9	$3.2\pm1.4_{stat}$



RIGHT: The flux (>260 GeV) measured by H.E.S.S. from 1ES 1101-232 in annual bins (2004-05 data from [4]). The x-errors reflect the observation dates. The average flux ($3.50\pm0.35_{stat}$ $\times10^{-12}$ cm^{-2} s^{-1}; line) from 2004-06 is above the 99.9% flux limit in 2007.

Low Altitude Observations of VHE AGN

Three northern AGN, known to emit VHE γ-rays, were observed briefly (good-quality live time, T<2.2 h) at low altitudes with HESS. The table below reports results for those observations. The data from 1ES 1218+304 and Mkn 501 are contemporaneous with data from the Suzaku X-ray satellite and the MAGIC VHE telescope. At high zenith angles, Z_{obs}, the energy threshold (E_{th}) of H.E.S.S. is higher and the sensitivity is reduced.

Object	Date	T [h]	Z_{obs} [deg]	Excess	Signif. [σ]	E_{th} [TeV]	I(>E_{th}) [10^{-12} cm^{-2} s^{-1}]	Crab [%]
Mkn 421	Apr 12, 2005	0.9	63	28	3.5	2.1	$3.1\pm1.0_{stat}$	45
1ES 1218+304	May 19, 2006	1.8	56	-9	1.2	1.0	<3.9	17
Mkn 501	Jul 18, 2006	2.2	64	9	-0.8	2.5	<1.1	22

Remarks on the Scientific Quantities

The H.E.S.S. standard analysis [3,6] is used for all results presented here. A power law spectrum with photon index Γ=3.0 is assumed for all flux quantities, with the exception of those for 1ES 1101-232 where Γ=2.94, as measured [4] in 2004-05, is chosen. Assuming a different Γ (i.e. 2.5 < Γ < 3.5) has less than a ~10% effect. All upper limits are calculated at the 99.9% confidence level (c.l.) using the method of Feldman & Cousins [8]. The percentage of the Crab Nebula flux, above the same threshold, is calculated from the H.E.S.S. Crab Nebula spectrum [3]. The systematic error on all flux quantities is 20%.

Acknowledgments & References

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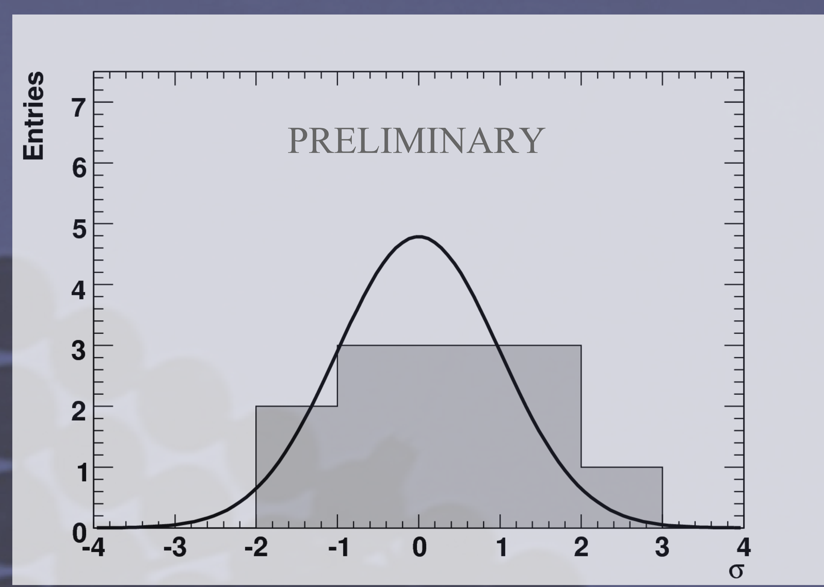
VHE Observations of 12 AGN

No significant excess of VHE γ-rays is found from any of the 12 candidate VHE-emitters presented below. Stacking the excess from all 12 AGN yields only 29 events (0.5σ). A search for serendipitous source discoveries in the H.E.S.S. f.o.v. centered on each of the AGN also yields no significant excess.

RIGHT: Distribution of the significance observed from 12 AGN. The curve represents a Gaussian distribution with zero mean and a standard deviation of one.



BELOW: The candidate AGN ordered by right ascension in groups of blazars and non-blazars. The coordinates (J2000) and type (BL=BL Lac, EGRET=EGRET Blazar, FSRQ=Flat Spectrum Radio Quasar, Sy=Seyfert, FR=Fanaroff-Riley) are shown. The good-data-quality live time observed (T), mean zenith angle of observation (Z_{obs}), the corresponding post-selection cuts energy threshold (E_{th}), the observed excess and significance (S) are also shown.

Object	α [hh mm ss]	d [dd mm ss]	Type	T [hours]	Z_{obs} [deg]	E_{th} [GeV]	Excess	S [σ]
Blazars								
III Zw 2	00 10 31.0	+10 58 30	HFSRQ	1.7	37	420	12	1.4
BWE 0210+116	02 13 05.0	+12 13 06	EGRET	6.0	43	530	-13	-0.9
1ES 0323+022	03 26 14.0	+02 25 15	HBL	7.2	27	300	13	0.7
PKS 0521-365	05 22 58.0	-36 27 31	EGRET	3.1	26	310	11	0.8
3C 279	12 56 11.2	-05 47 22	EGRET	2.0	26	300	5	0.5
RBS 1888	22 43 42.0	-12 31 06	HBL	2.4	15	240	30	2.2
PKS 2316-423	23 19 05.9	-42 06 49	IBL	4.1	20	270	29	1.6
1ES 2343-151	23 45 37.8	-14 49 10	IBL	8.6	17	230	-16	-0.6
Non-blazars								
NGC 1068	02 42 40.8	-00 00 48	Sy II	1.8	29	330	9	1.1
Pictor A	05 19 49.7	-45 46 45	FR II	7.9	31	320	-23	-1.1
PKS 0558-504	05 59 46.8	-50 26 39	Sy I	8.3	28	310	-14	-0.7
NGC 7469	23 03 15.8	+08 52 26	Sy I	3.4	34	330	-14	-1.3

VHE Flux Upper Limits for 12 AGN

The integral flux upper limits (99.9% c.l.; Units are 10^{-12} cm^{-2} s^{-1}) below constrain the maximum average brightness of the AGN only during the observation time (dates given). Hence they should be interpreted as limits 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. It should be noted that no evidence for VHE flux variability is observed from any of the 12 AGN, and none of these AGN (for which RXTE/ASM data exists) were particularly active in X-rays during the H.E.S.S. observations.

Blazars	Redshift	MJD-50000	E_{th} [GeV]	I(>E_{th})	Crab %
III Zw 2	0.089	3944, 3953	420	5.36	6.4
BWE 0210+116	0.250	3966-69, 3971, 3974, 3976-78	530	0.72	1.2
1ES 0323+022	0.147	3668-69, 3676-78, 3998-4000	300	2.52	1.9
PKS 0521-365	0.0553	4079-4081	310	5.40	4.2
3C 279	0.536	4118-4121	300	3.98	2.9
RBS 1888	0.226	3914, 3916-18	240	9.26	4.9
PKS 2316-423	0.055	3919-23	270	4.74	3.0
1ES 2343-151	0.224	3592-95, 3597	230	2.45	1.2
Non-Blazars					
NGC 1068	0.00379	4022, 4024, 4032	330	5.76	4.9
Pictor A	0.0342	4051-54, 4056-57, 4060-64	320	2.45	2.0
PKS 0558-504	0.137	4110-4113, 4115-16, 4121	310	2.38	1.8
NGC 7469	0.0164	4020-21, 4023-24, 4032	330	1.38	1.2

Conclusions

Results presented here describe the H.E.S.S. AGN observations for which no significant excess is found, apart from marginal signals from the known VHE emitters Mkn 421 and 1ES 1101-232. Despite the limited exposure (4.7 hours on average) for each of the 12 VHE candidates, the upper limits on the VHE flux determined by H.E.S.S. are either the most stringent to date, or only surpassed by limits [1] from H.E.S.S. observations in 2004. Clearly the strength of these limits makes them quite useful. However, it must be stressed that any interpretation using the H.E.S.S. results must take into account both the EBL and the state of the source using simultaneous data at different wavelengths. The existence of contemporaneous Suzaku X-ray data make the flux limits on Mkn 501 and 1ES 1218+304, and the flux from 1ES 1101-232 particularly useful for modeling.

With the detection of ten VHE AGN, including seven not previously detected in the VHE regime, the H.E.S.S. AGN observation program has been highly successful. However, despite almost five years of observations, the AGN program is not complete. Some proposed candidates have not yet been observed and others have received only a small fraction of their requested exposure. Clearly the prospects of finding additional VHE-emitting AGN are excellent. In addition, more H.E.S.S. observations are planned to monitor the flux from known VHE AGN and identify exceptional VHE flares (see, e.g., [5]).

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