AGN Observations with H·E·S·S·

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Abstract.
H·E·S·S· (High Energy Stereoscopic System) is fully operational since December 2003. Two AGNs have been detected since the first telescope became operational (June, 2002): PKS 2155-304 and Mkn 421. The BL Lac PKS 2155-304 at redshift $z = 0.117$ has been observed for over 80 hours during 2002 (mono mode) and 2003 (stereo). The source was found to be active in all periods of observation with a steep spectrum. In early April 2004, flaring activity of Mkn 421 was detected in X-rays with the All-Sky Monitor (ASM) aboard the Rossi X-ray Timing Explorer (RXTE) satellite. Mkn 421 has subsequently been monitored with the H·E·S·S· array at very large zenith angles. We will report here on the analysis of these data from H·E·S·S· together with the multiwavelength campaigns on these sources.

INTRODUCTION

H·E·S·S· (High Energy Stereoscopic System) is fully operational since December 2003. With a much better sensitivity and a lower energy threshold compared to the first generation Cherenkov telescopes, H·E·S·S· allows significantly improved measurements of TeV emission from Blazars. Two AGN have been detected since the first telescope became operational (June, 2002): PKS 2155-304 and Mkn 421.

The high-frequency peaked BL Lac object PKS 2155-304, with a redshift of $z = 0.117$, is the strongest source in southern sky. This is the second most distant object detected at TeV energies, therefore its energy spectrum may exhibit characteristics such as steepening of the spectrum and a cut-off caused by absorption of VHE gamma rays via pair production on the Extragalactic Background light (EBL).

Markarian 421 is the closest known BL Lac ($z = 0.031$) and is a well-established very high energy γ-ray source in the Northern sky. This observation at very low elevation by H·E·S·S· will give new constrains at very high energy.

OBSERVATIONS OF PKS 2155-304

The H·E·S·S· observations of PKS 2155-304 were made while the system was under construction, therefore the data cover various telescope configurations and trigger criteria. In 2002 a single telescope took observations in ON-OFF mode. In 2003, observations were made in a two-telescope configuration until September, when a third telescope was added to the array. The system-level trigger was installed in July 2003, before which

TABLE 1. Observations of PKS 2155-304. SW or HW stereo denote Software stereo (events matched by GPS time) and Hardware stereo (matching by central trigger electronics)

Dark Period	Config -uration	Multiplicity (#tels/total)	Observing Mode	Time (hrs)	E_{th} (GeV)	Rate (γ/min)	Significance (σ)
07/2002	Mono	1/1	On-Off	2.5	300	2.55	13.0
10/2002	Mono	1/1	On-Off	4.3	300	1.22	8.2
11/2002	Mono	1/1	On-Off	0.8	300	-0.01	-0.1
06/2003	SW Stereo	2/2	Wobble	10.8	260	1.08	21.1
07/2003	HW Stereo	2/2	Wobble	22.1	170	0.88	22.1
08/2003	HW Stereo	2/2	Wobble	19.6	170	1.24	27.7
09/2003	HW Stereo	2/2	Wobble	0.9	160	1.59	6.7
09/2003	HW Stereo	2/3	Wobble	2.1	160	3.35	14.7

two-telescope data were taken with each telescope separately and the stereo multiplicity requirement was performed off-line using GPS time stamps.

The stereo data were taken in 28-minute runs using “wobble” mode. The source direction is positioned ± 0.5 degrees in declination relative to the centre of the field of view of the camera during observations. The sign of the offset is alternated in successive scans to reduce systematic effects.

The fourth and final telescope were added to the array in December 2003, after the end of the observation season for PKS 2155-304. Details of the H·E·S·S· observations of PKS 2155-304 which pass conservative run selection criteria are summarized in Table 1.

Data analysis and results

After a first image cleaning, the moments of the shower image are parametrized using Hillas-type analysis. In the mono-telescope case, the impact parameter and direction of the shower axis are estimated directly from the image. For the other configurations, the shower geometry is reconstructed using stereoscopic techniques with a typical angular resolution of 0.1° and an average accuracy of 10% in the determination of the shower core location.

Image shape and orientation parameters obtained after this moment analysis are then used to discriminate against the cosmic-ray background. Cut values are defined for the Hillas parameters by optimisation on a simulated γ-ray spectrum against real background events [2]. The much more numerous cosmic-ray background events are rejected using cuts on mean reduced scaled width, length, and a cut on θ^2, the square of the angular difference between the reconstructed shower position and the source position.

Images from muons are rejected by requiring events be coincident in at least two telescopes in the stereo configuration. The background estimation uses events passing the cuts, during the off-source observations at the centre of the field of view for the mono data, and in a ring (with an area of approximately seven times the area of the on-source region and a radial centre at 0.5° from the source position) around the source location for “wobble” data taken in stereo mode [1]. For the stereo configuration, a minimum of two telescopes passing the cuts is required for a successful reconstruction. PKS 2155-304 is strongly detected by H·E·S·S· in all the periods in which it was observed with the exception of November 2002, where the exposure was less than one hour. The total significance of the excess for all observations is 44.9σ,which give $5.7\sigma/\sqrt{\text{hr}}$, and in average $1.20 \pm 0.03\gamma/\text{min}$.

Figure 1(a) shows the on-source and normalized off-source distributions of θ^2 for all observations in the two-telescope hardware stereo configuration. The background is flat in θ^2 as expected, and there is a clear excess at small values of θ^2 corresponding to the observed signal. Figure 1(b) shows a two-dimensional sky map of the excess observed in the direction of PKS2155-304 for the same configuration. The bins are not correlated and represent the actual distribution of the observed γ-ray on the sky.

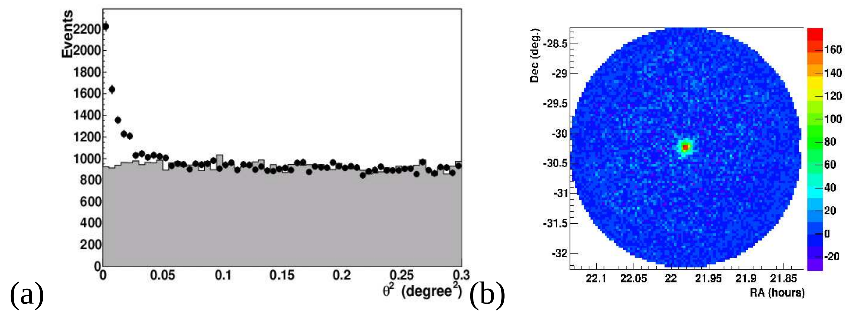


FIGURE 1. For PKS2155-304 (a) θ^2 distribution (b) 2D distribution of γ-ray candidates

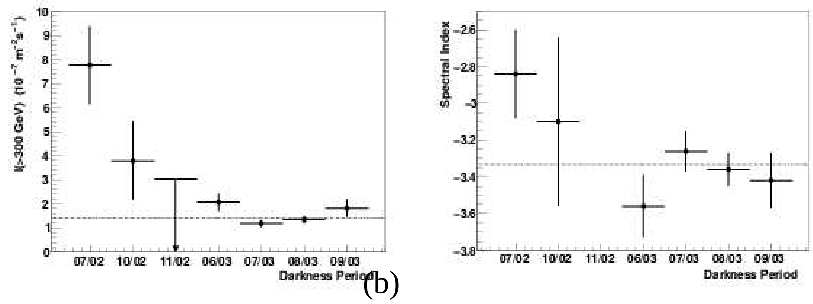
Spectrum and flux variability

PKS 2155-304's spectrum has been reconstructed for each dark period [1]. The integral flux above 300 GeV and the spectral index have been measured for each dark period as shown figure 2. The dashed line in each plot represents the results from a χ^2 fit of the data to a constant. The data are clearly inconsistent with a constant flux. The fit of the spectral index versus observation period is marginally consistent with a constant. Therefore, there is no evidence that the spectral index of PKS 2155-304 varies with time.

A correlation between harder spectral index and higher flux values might be expected for PKS 2155-304. We can not conclude with these data, and therefore further observations with the more sensitive complete H·E·S·S· array are needed to make a definitive statement regarding any correlation.

A time-averaged energy spectrum has been made for the 2003 stereo data as plotted on figure 3 [1]. The spectrum has been fitted using three different hypotheses:

- Power law (PL): $\frac{\mathrm{d}N}{\mathrm{d}E} = I_0 [E]^{-\Gamma}$,
  where I_0 is the differential flux normalisation, E is in TeV and Γ is the spectral index of the source.



(a) (b)

FIGURE 2. For PKS2155-304 (a) Integral flux above 300 GeV versus time mesured for 2003 data (b) spectral index versus time mesured for 2003 data

- Power law with exponential cut-off (PL-Exp): $\frac{\mathrm{d}N}{\mathrm{d}E} = I_0\,[E]^{-\Gamma} \exp\left[\frac{E}{E_{\mathrm{cut}}}\right]$, where E_{cut} is the cutoff energy (TeV) and E is in TeV.
- Broken Power law (BPL): $\frac{\mathrm{d}N}{\mathrm{d}E} = I_0 E_{\mathrm{break}}^{-\Gamma-\beta}\,[E]^{\beta}$, where E_{break} is the energy of the break point in TeV, β is the second spectral index and E is in TeV.

The result of these fits are presented in Table 2:

	χ^2	d.o.f.	Γ	E_{cut} or E_{break} (TeV)	I_0 $(m^{-2}s^{-1}TeV^{-1})$	β
PL	10.8	7	3.32 ± 0.06		$1.96 \pm 0.12 \cdot 10^{-8}$	
PL-Exp	6.2	6	$2.90^{+0.23}_{-0.21}$	$1.4^{+0.8}_{-0.7}$	$4.0^{+1.9}_{-1.2} \cdot 10^{-8}$	
BPL	5.1	5	$3.15^{+0.12}_{-0.10}$	0.7 ± 0.2	$2.4^{+1.9}_{-1.2} \cdot 10^{-8}$	$-3.79^{+0.27}_{-0.46}$

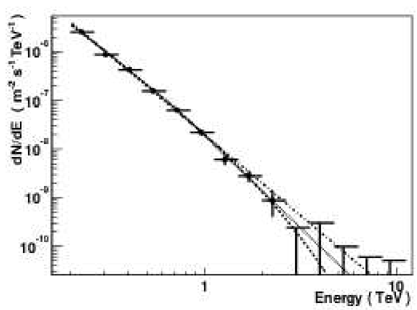


FIGURE 3. Preliminary time averaged spectral energy distribution of PKS2155-304 for 2003 stereo data.

The exponential cut-off and the broken power law could be the result of absorption by EBL or be intrinsic to the source. However, for these observations, there is no significant deviation from a power law.

Multiwavelength observations

An in-depth multifrequency ToO campaign, we have sampled the TeV emission over two orders of magnitude in energy simultaneously with continuous coverage of the synchrotron radiation in the X-ray, optical, and radio bands. A Target of Opportunity (ToO) observation with the RXTE satellite was triggered by H·E·S·S· in October 2003 due to exceptional source activity.

We have quasi-simultaneous observations: 114 hours in October (2/3 telescopes) and 5 hours in November. The data are currently being analysed in order to determine if there are some correlations between X and γ-ray in the variability of the source. Figure 4 shows a preliminary multiwavelength energy distribution for PKS 2155-304 with H·E·S·S· data in γ-rays and RXTE in X-ray. Historical EGRET data have been added in order to show what could be the future contribution from GLAST in the same energy range to constrain the models.

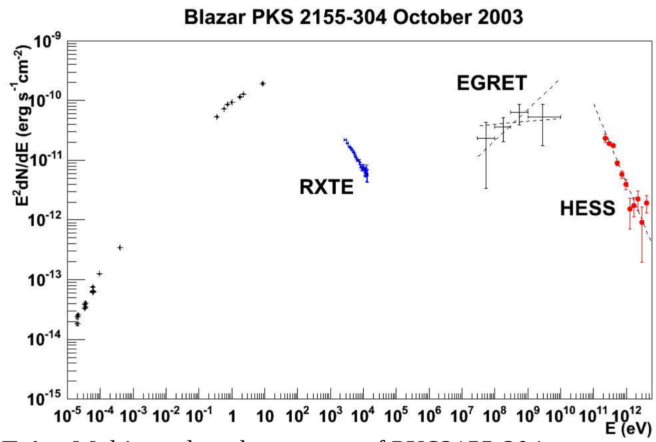


FIGURE 4. Multiwavelength spectrum of PKS2155-304

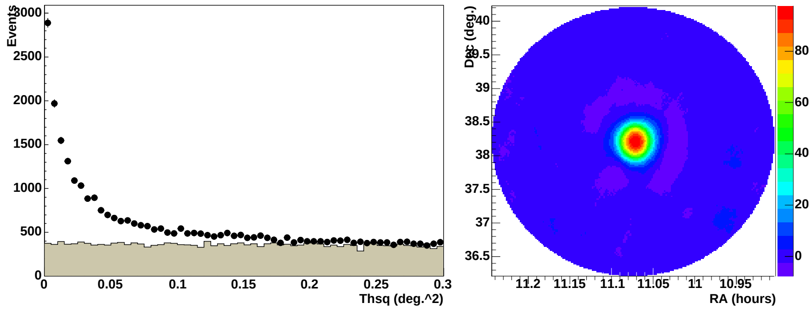
The goal of such extended broad-band observations is to obtain accurate and dense light curves of the source flaring activities, which will enable us to model the particle distribution in the jet [3]. Moreover, long-term observations at lower frequencies will help to model the full temporal evolution of the flares, to possibly pin down the spatial particle distributions and actual acceleration mechanisms in the jet and to know if an intrinsic cut-off in the particle spectrum is due to the EBL or to an internal absorption.

DETECTION OF MKN 421

The VHE emission from Mkn 421 is extremely variable, showing flaring activity on time scales as short as 15 minutes. H·E·S·S· observed this northern source at very low elevation, the source culminates at zenith angle higher than 60°. All Mrk 421 data are taken with four telescopes at average zenith angle 62°.

In Janurary 2004, the source was detected in a low state: 6σ in 2.12 hours. In April 2004 the source has been detected in an active state, with an excess of 8167γs in 11.5 hr, for a total of 95.7σ, with 11.8γ per minute on average. Figure 5 shows the θ^2 distribution and the 2D sky map of these observations.

At very large zenith angle the collection area becomes very large and the threshold very high, it gains a factor of $1/\cos\theta^2$ due to the depth of atmosphere crossed by the Cherenkov emission and ground area projection. We can have large statistics, study fast the spectrum and constrain the models at very high energy. However, this observation



(a)

FIGURE 5. For Mkn 421 (a) θ^2 distribution (b) 2D distribution of γ-ray candidates

is technically difficult because of the systematics due to large depth of atmosphere traversed.

CONCLUSION

Two AGN have been detected since the first HESS telescope became operational (June, 2002): PKS 2155-304 and Mkn 421.

PKS 2155-304 is strongly detected in all the dark periods, from June to September with an average significance of $5.7\sigma/\sqrt{}$hr and $1.20 \pm 0.03\gamma$/min.
The spectrum has been reconstructed for each dark period, the flux varies with time but there is no evidence that the spectral index of PKS 2155-304 varies with time. A time averaged energy spectrum has been made for the 2003 stereo data, the power-law fit gives a flux of $\mathrm{I}(1\mathrm{TeV}) = 1.96 \pm 0.12.10^{-8}\mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{TeV}^{-1}$ and an index of $\Gamma = -3.32 \pm 0.06$. There is no strong evidence for deviation from a power law. Mkn 421 has been detected in an active state at very low elevation by H·E·S·S·with an excess of 8167γ in 11.5 h and a rate of 11.8γ per minute. These observations will help us to constrain the models at very hight energy.

These two first blazars detections will give great improvements in AGN models, and these first results are encouraging for future prospects.

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