Discovery of an unidentified TeV source in the field of view of PSR B1259-63 with H.E.S.S.

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Abstract. The detection of an unidentified extended TeV γ-ray source in the Southern Cross region close to the galactic plane being named HESS J1303-631 is reported. The observations have been performed between February and June 2004 with the new stereoscopic system of four Cherenkov telescopes operated by the H.E.S.S. collaboration in Namibia. The telescopes were initially pointed to the binary system PSR B1259-63/SS 2883 which was for the first time detected at TeV energies within this observation campaign (see parallel paper). In the same dataset the unidentified TeV source HESS J1303-631 has been discovered serendipitously roughly 0.6° north of the PSR B1259-63 position leading – for the first time in TeV γ-ray astronomy – to the detection of two sources within the same field of view. The new source is extended on the 0.2° level and – up to now – no counterpart in other wavelengths has been identified. The measured flux is compatible with constant emission on the 10 % flux level of the Crab nebula and shows a hard energy spectrum which can be described by a power-law with an index of $\Gamma = 2.2 \pm 0.2_{\mathrm{stat}}$. In this paper various consistency checks which confirm the celestial origin of the observed excess are presented and preliminary results on the source extension and energy spectrum of the source are reported.

INTRODUCTION

The High Energy Stereoscopic System (H.E.S.S.) experiment consists of an array of four imaging atmospheric Cherenkov telescopes (IACTs) located in Namibia at 1800 m a.s.l. [1]. Each telescope has a 107 m^2 tessellated mirror surface and is equipped with a 960 photomultiplier tube (PMT) camera with a field of view diameter of $\sim 5°$ [2]. The telescopes are operated in coincidence (stereoscopic mode) well suited together with the large field of view to perform searches for TeV γ-ray sources in sky regions of more than $3° \times 3°$ centered around the telescopes tracking position.

A search for a priori unknown objects in the field of view has been performed in the PSR B1259-63/SS 2883 dataset taken between February and June 2004. The observations on this exceptional binary system led – for the first time – to a detection of this object at TeV energies near periastron [3, 5]. The search for unknown objects in the field of view resulted in the unexpected discovery of a second TeV γ-ray source being named HESS J1303-631 at a sky position roughly 0.6° north of PSR B1259-63/SS 2883.

OBSERVATIONS & RESULTS

Dataset

The H.E.S.S. observations have been performed in runs of 28 min duration in the moonless parts of the night in the so-called *wobble* mode. In this mode the telescopes are pointed to an alternating offset position of $\pm 0.5^\circ$ in Right Ascension or Declination with respect to the nominal source position (in this case the PSR B1259-63/SS 2883 position of the initial observation) allowing for an unbiased simultaneous background determination.

The observations which started on February 26, 2004 were extended up to June 2004 following the detection of the binary system PSR B1259-63/SS 2883 and the discovery of the second TeV source HESS J1303-631 in the same field of view a few weeks later. Meanwhile, the whole dataset comprises more than 75 h of data. The telescope tracking was changed to a new sky-position in May 2004 optimized also for the new source HESS J1303-631. All tracking positions are illustrated in Fig. 1.

The calibration of the data is described in [4]. The same standard run quality cuts (stable weather and detector status) have been applied to the data as for the PSR B1259-63/SS 2883 analysis described in [5], see [6] for details of the analysis technique. For the first observation period between February 26 and March 5, 2004 one of the four telescopes (CT1) had to be excluded from the analysis due to technical reasons.

Consistency checks

Although HESS J1303-631 is located very close to the galactic plane, the detection of a second TeV source (following PSR B1259-63/SS 2883) in the same field of view was quite unexpected. Therefore, a lot of additional consistency checks have been applied to the data covering the time span from March[1] to June 2004 to confirm the celestial origin of the measured excess (using standard cuts for point-sources optimized on Monte Carlo data). The background was determined using the template background model [7] and was cross-checked with the ring background model. The most important results are summarized in Tab. 1 and are shortly discussed in the following paragraph:

- *Excluding individual telescopes* (CT1 - CT4) slightly decreases the significance (as expected). Results between the individual subsets are compatible which excludes the contribution of a specific telescope to the excess in an unexpected manner.
- *Results from different tracking positions* (compare Fig. 1, right) are compatible. This excludes the excess to be due to a local camera effect which could translate into a reconstruction to a given sky-position in a systematic way.
- *Different observation periods* between March and June 2004 yielded compatible results (implying constant emission of HESS J1303-631, compare Fig. 3, left) which

[1] Since CT1 was excluded from the analysis between February 26 and March 5, 2004 these data have been generally excluded from the consistency checks in order to guarantee a homogeneous dataset.

TABLE 1. Results of various consistency checks applied to the HESS J1303-631 data. Shown are for the different data sets the corresponding number of excess events, lifetime, significance per square root hour $\sigma/\sqrt{h}$ and the distance $d = |\vec{r}_{\mathrm{subset}} - \vec{r}_{\mathrm{all}}|$ between the excess mean position of the specific dataset compared to the mean position of the whole dataset.

subset	excess events	lifetime	$\sigma/\sqrt{h}$	d in arc min
excluded telescope				
CT1 / CT2	655 ± 55 / 642 ± 54	37.1 h	2.1 / 2.1	0.8 ± 0.8 / 0.8 ± 0.7
CT3 / CT4	758 ± 55 / 795 ± 55	37.1 h	2.4 / 2.6	1.6 ± 0.7 / 0.8 ± 0.7
tracking positions*, see Fig. 1				
$\mathrm{Dec}_{\mathrm{i}}^{-}$ / $\mathrm{Dec}_{\mathrm{i}}^{+}$	229 ± 30 / 297 ± 36	~ 10 h	2.7 / 2.9	1.2 ± 1.2 / 1.2 ± 1.4
$\mathrm{RA}_{\mathrm{n}}^{-}$ / $\mathrm{RA}_{\mathrm{n}}^{+}$	150 ± 27 / 196 ± 27	~ 7.5 h	2.2 / 2.9	1.0 ± 1.7 / 1.6 ± 1.7
image multiplicity $m^{\dagger}$				
$m = 2$ / $m \geq 2$	351 ± 51 / 950 ± 63	37.1 h	1.2 / 2.6	1.3 ± 1.8 / 0.0 ± 0.7
$m = 3$ / $m \geq 3$	227 ± 29 / 651 ± 41	37.1 h	1.4 / 3.0	0.7 ± 1.3 / 0.1 ± 0.6
$m = 4$ / $m \geq 4$	428 ± 30 / 428 ± 30	37.1 h	2.8 / 2.8	0.9 ± 0.7 / 0.9 ± 0.7
image amplitude a **[p.e.]**				
$80 < a < 500$ / $a > 500$	889 ± 66 / 201 ± 16	37.1 h	2.3 / 2.8	1.8 ± 0.7 / 2.0 ± 0.8

* The tracking modes $\mathrm{RA}_{\mathrm{i}}^{+}$ and $\mathrm{RA}_{\mathrm{i}}^{-}$ wobbled in Right Ascension with respect to the PSR B1259-63/SS 2883 position have not been used in this investigation since they only amount to ~ 1.5 h each.

† Note that due to different background normalizations α in the subsets (excess $= N_{\mathrm{on}} - \alpha \cdot N_{\mathrm{off}}$) the sum of the excess is not completely identical compared to the excess of the whole data.

excludes a temporary environment effect (i.e. lightnings, external light source, etc.).

- *Cuts on different image multiplicities m* have been applied to the data ($m \geq 2$, $m = 2$, $m \geq 3$, $m = 3$, and $m = 4$ images in an event). The contribution of each multiplicity to the overall signal is for HESS J1303-631 within expectations.
- *Different image amplitude intervals* have been analysed confirming the obtained hard energy spectrum (compare with Fig. 3, right). This excludes conceivable effects being correlated with a given image amplitude regime only.
- *The distribution of the image center of gravity (COG)* of the Hillas ellipses contributing to the excess does not show any irregularities in any of the cameras.
- *The mean scaled width (mscw)* parameter of an event is derived by averaging the image widths obtained from different telescopes which have been scaled by their Monte Carlo expectation values. For a real γ-ray signal the distribution of this parameter (which is used for γ-hadron separation) follows a gaussian function $a \cdot \exp[-(x - x_0)/2\sigma^2]$ with $\sigma = 0.1$ and a mean position of $x_0 = 1.0$ (obtained from Monte Carlo simulations). This is fulfilled for the HESS J1303-631 excess as shown in Fig. 2, left.

Additionally to the above mentioned systematic tests, different analysis techniques[2] have been applied to the data using the Hillas parameter based standard analysis [6] and a model-based analysis [8, 9]. The results obtained from these different techniques are

[2] These start differing at an independent data calibration chain [4] being followed by completely different shower reconstruction and gamma hadron separation algorithms.

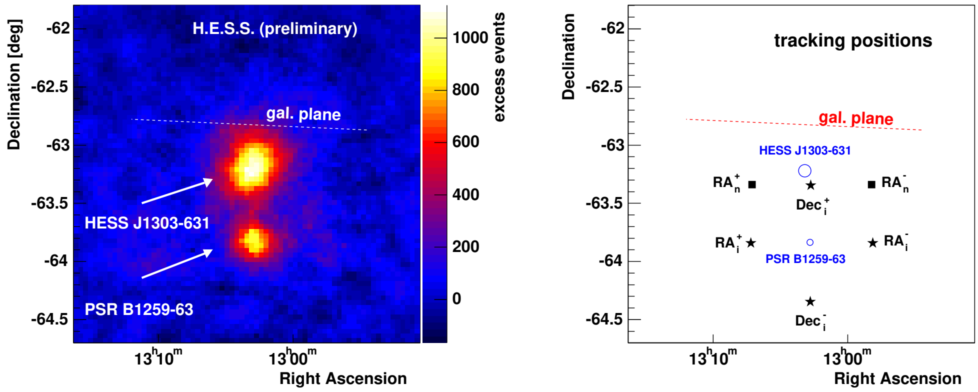

FIGURE 1. *Left:* The discovery skymap (excess events) showing HESS J1303-631 and PSR B1259-63/SS 2883 (correlated bins integrated over the optimal angular cut of $\Theta < 0.14°$, using the ring background model). *Right:* The positions of the two TeV sources (open circles) as well as the six different tracking positions of the observations are indicated. In May 2004 the initial tracking positions (index i, stars) were changed to the new positions (index n, squares) optimized for both TeV sources.

in good agreement.

The results of the various consistency checks and of the different analysis chains as well as the shape of the *mscw* distribution fulfill the expectations for a γ-ray signal. A statistical fluctuation can be excluded due to the high significance of $\sim 20\,\sigma$ of the excess (see next section).

Results

For the results presented here data taken between March and May 2004 have been used comprising ~ 45 h of good quality data. The discovery skymap including HESS J1303-631 as well as the binary system PSR B1259-63/SS 2883 is shown in Fig. 1, left. The HESS J1303-631 position which was used for the following investigations has been derived by fitting a 2D gaussian function to the (uncorrelated) excess skymap and was found to be $\alpha_{\mathrm{J2000.0}} = 13\,\mathrm{h}\,03\,\mathrm{m}$, $\delta_{\mathrm{J2000.0}} = -63.2\,\mathrm{deg}$ (a more precise value will be given in a forthcoming paper [10]). The analysis performed relative to this position results in 1055 ± 67 excess events corresponding to a significance of $16.6\,\sigma$ calculated following [11]. These numbers were obtained with analysis cuts optimized for point-sources. As indicated in Fig. 2 (right) the width σ of a function $N(\Delta\Theta^2) = a + b \cdot \exp(-\Delta\Theta^2/2\sigma^2)$ which was fit to the excess distribution shows a significantly larger value than the expected width of a point-source which is in the order of $\sigma_{\mathrm{psf}} \approx 0.07°$ (indicated by the dotted line). Therefore, it can be concluded that HESS J1303-631 is extended with an estimated extension (RMS) in the order of $0.2°$. Adjusting the angular cut for the source extension from $\Delta\Theta^2 < 0.02\,\mathrm{deg}^2$ to $\Delta\Theta^2 < 0.05\,\mathrm{deg}^2$ one obtains ~ 2000 excess events on the $20\,\sigma$ level. The excess grows steadily with time, resp. accumulated background (see Fig. 3, left), indicating constant emission from HESS J1303-631.

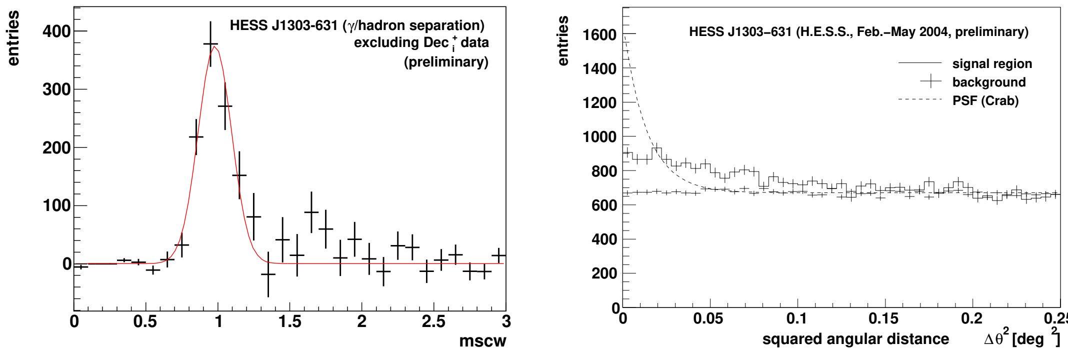

FIGURE 2. *Left:* Distribution of the *mscw* parameter (used for γ-hadron separation) for the HESS J1303-631 excess (excluding the $\mathrm{Dec}_\mathrm{i}^+$ data in which the excess position is close to the camera center). The line is a fit by a gaussian function with $\sigma = 0.12 \pm 0.01$ and a mean position of $x_0 = 0.98 \pm 0.01$ (solid line) as expected for a real γ-ray signal. *Right:* Number of events vs. the squared angular distance $\Delta\Theta^2$ between reconstructed shower direction and the nominal source position for the HESS J1303-631 region (histogramm) and for the normalized background region (single points). The expected distribution for a point-source (PSF) with the same number of excess events is indicated by the dotted line.

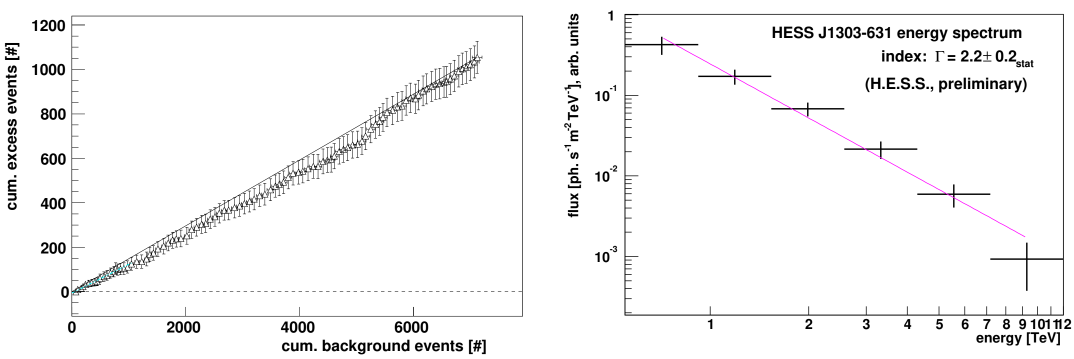

FIGURE 3. *Left:* The cumulative number of excess events vs. the cumulative number of background events indicating a constant emission from HESS J1303-631. *Right:* The differential energy spectrum of HESS J1303-631 (only $\mathrm{Dec}_\mathrm{i}^-$ data were used) given in arbitrary units. The shape can be described by a power-law $\mathrm{dN}/\mathrm{dE} \sim \mathrm{E}^{-\Gamma}$ with an index of $\Gamma = 2.2 \pm 0.2_\mathrm{stat}$ (systematic errors are under investigation).

A differential energy spectrum was obtained applying the relaxed angular distance cut, see Fig. 3, right. Only the $\mathrm{Dec}_\mathrm{i}^-$ wobble data (comprising ~ 14h) were used for the spectrum shown in this paper. It can be fitted by a power-law $\mathrm{dN}/\mathrm{dE} \sim \mathrm{E}^{-\Gamma}$ with an index of $\Gamma = 2.2 \pm 0.2_\mathrm{stat}$ (systematic errors are under investigation). The flux was estimated to be on the 10 % flux level of the Crab nebula. A more detailed analysis of the data will be presented in an upcoming paper [10].

SUMMARY & CONCLUSION

Following the detection of the exceptional binary system PSR B1259-63/SS 2883 in March 2004 another TeV source being named HESS J1303-631 was discovered in the same field of view at a position of $\alpha = 13\,\mathrm{h}\,03\,\mathrm{m}$, $\delta = -63.2\,\mathrm{deg}$ (J2000.0). The celestial origin of the measured excess was underlined by a variety of applied and successfully passed consistency checks. For the first time in TeV γ-ray astronomy two sources have been found within one field of view. The emission of HESS J1303-631 is compatible with a constant flux on the 10 % flux level of the Crab nebula. The energy spectrum can be fitted by a power-law $\mathrm{dN}/\mathrm{dE} \sim \mathrm{E}^{-\Gamma}$ and was found to be rather hard with an index of $\Gamma = 2.2 \pm 0.2_{\mathrm{stat}}$. Clear indication for extension on the 0.2° level was found. A more detailed investigation of the source will be subject of an upcoming paper [10].

Up to now no counterpart in other wavelength has been found. Therefore, HESS J1303-631 is the second unidentified TeV γ-ray source discovered, following TEV J2032+4130 discovered in the Cygnus region by HEGRA [12]. This might open a window to a new class of (most probably galactic) TeV γ-ray sources. For the understanding of the underlying physics future multiwavelength observations will play an important role.

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