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Detection of a yet unidentified TeV γ-ray Source HESS J1303-631 with the H.E.S.S. Cherenkov telescopes

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Following the detection of the binary system PSR B1259-63/SS 2883 at TeV energies, another TeV source named HESS J1303-631 has been discovered serendipitously at a significance of 21 standard deviations close to the galactic plane in the same field of view of the H.E.S.S. Cherenkov telescopes. The data were taken between February and June 2004. The source is extended with $\sigma = (0.16 \pm 0.02)^\circ$ and the integral flux above 380 GeV was found to remain on a constant level of $(17 \pm 3)\%$ of the flux level of the Crab Nebula during the observation periods from February to June, 2004. Up to now, no counterpart at other wavelengths is found. This makes HESS J1303-631 the second unidentified TeV γ-ray source following TEV J2032+4130 discovered in the Cygnus region by HEGRA.

1. INTRODUCTION

The binary system PSR B1259-63/SS 2883 was observed with the new H.E.S.S. (High Energy Stereoscopic System) Cherenkov telescopes close to its periastron passage starting in February 2004. The February/March observation period led to the first detection of this exceptional binary system at TeV energies [1, 2].

Surprisingly, another TeV γ-ray source located at a position roughly 0.6° north of the position of the binary system was discovered in the same field of view (see Fig. 1), given the name of HESS J1303-631. The detection and basic features of this new source are reported in this paper.

2. THE H.E.S.S. EXPERIMENT

The H.E.S.S. collaboration operates an array of four imaging atmospheric Cherenkov telescopes (IACTs) optimized for an energy range of γ-rays between 100 GeV and 20 TeV located in Namibia ($23^\circ 16^\mathrm{m} 18^\mathrm{s}$ S, $16^\circ 30^\mathrm{m} 1^\mathrm{s}$ E) at a height of 1 800 m above sea level. Each telescope has a 107 m^2 tessellated mirror surface [3, 4] and is equipped with a 960 photomultiplier tube camera with a field of view diameter of $\sim 5^\circ$ [5] which allows searches and studies of TeV γ-ray sources in sky regions of more than $3^\circ \times 3^\circ$ per pointing. The telescopes are operated in a coincident mode [6] assuring that an event is always recorded by at least two of the four telescopes allowing for stereoscopic reconstruction of the shower parameters and an improved γ-hadron separation. More information about H.E.S.S. can be found in [7].

3. DATASET

The data were taken between February and June 2004 with the fully operational H.E.S.S. IACT array. The average zenith angle of the observations was 42.7° yielding an energy threshold of $E_\mathrm{thr} = 380\,\mathrm{GeV}$ defined by the peak γ-ray detection rate of a Crab-like spectrum after event selection cuts. The observations were performed in the *wobble* mode tracking a position shifted by ±0.5° in Declination or Right Ascension with respect to the nominal source position (in this case the PSR B1259-63/SS 2883 position of the initial observation campaign), allowing for an unbiased simultaneous background determination. Following the detection of HESS J1303-631 in the PSR B1259-63/SS 2883 field of view, the telescope tracking positions were changed to new sky positions in May 2004, optimized for both sources by choosing the wobble modes with respect to a position located between PSR B1259-63/SS 2883 and HESS J1303-631. The initial pointing positions (filled stars) as well as the new pointing positions (empty triangles) are shown in the right hand panel of Fig. 1. The data were selected by standard quality criteria (stable weather and detector status) leaving 54.5 hours of data (48.6 h detector life time) for the final analysis. For the data taken between February 26 and March 5, 2004, one of the

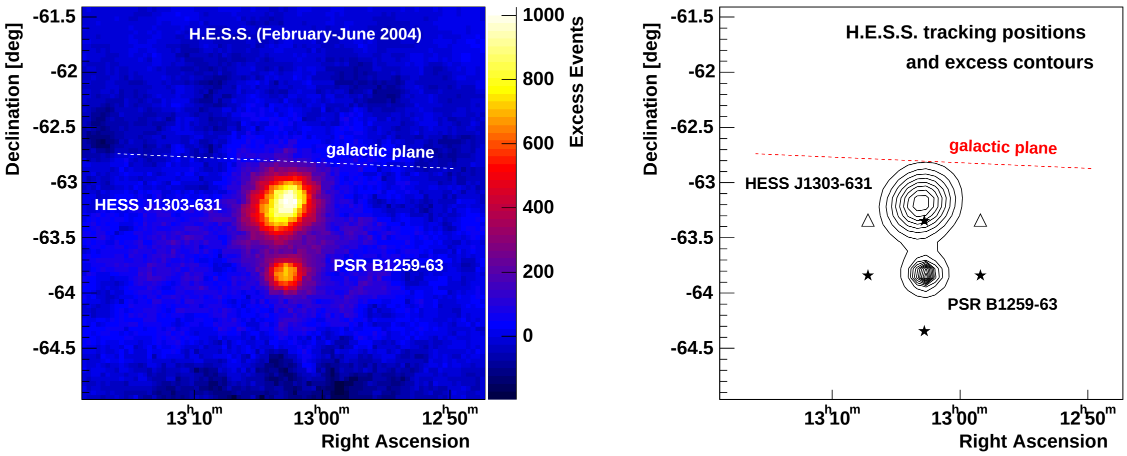

Figure 1: *Left:* The sky map showing both TeV sources: HESS J1303-631 and PSR B1259-63/SS 2883. The Galactic plane is also indicated. The events are integrated within the optimal point-source angular cut of $\Theta \leq 0.14°$ for each of the correlated bins. *Right:* The function which was fitted to the (uncorrelated) excess sky map is drawn as contours. Also shown are the different H.E.S.S. tracking positions: Filled stars indicate the initial tracking positions and the empty triangles the optimized positions which were used since May, 2004.

four telescopes was excluded from the analysis due to technical reasons; the remaining data (March to June 2004) were taken with the full array of four telescopes. The raw data were subject to the standard calibration [8] and Hillas parameter-based analysis [9].

4. RESULTS

4.1. Discovery and cross-checks

Shortly after the discovery of the binary system PSR B1259-63/SS 2883 the highly significant excess of the second source HESS J1303-631 was found in the data. The discovery sky map resolving both TeV sources is shown in the left hand panel of Fig. 1. The number of excess events was calculated using the ring background model in which the background is determined from a ring region with a radius $r > 0.5°$ centered around the putative source position. Both TeV γ-ray source regions were excluded from the background region to avoid background contamination by real γ-ray events. In order to improve the angular resolution for the investigation of the position and extension, at least three images were required per event for the sky map.

A wide range of consistency checks was applied and successfully passed underlining the celestial origin of the measured excess. For this purpose the data were divided into different subsets and the results (source strength, excess position, etc.) were compared. The subsets were chosen according to the different observation periods (from February to June, 2004) and the different telescope tracking positions (compare Fig.1, right). Different cuts on the telescope multiplicity m ($m \geq 2$, $m = 2$, $m \geq 3$, $m = 3$ and $m = 4$) for individual events as well as different cuts on the image amplitude were applied to the data. Also, individual telescopes in turn were excluded from the analysis. Finally, the distribution of the *mean reduced scaled width (MRSW)* parameter which is used for the γ-hadron separation [9] was compared to the distribution of Monte Carlo simulated γ-showers and was found to be in good agreement. In all these checks the excess behaved as a genuine γ-ray source confirming the celestial origin of the measured excess from HESS J1303-631; more details on the consistency checks can be found in [10].

4.2. Position and excess

To obtain the position of HESS J1303-631 a function describing the excess of the two sources in the field of view was fitted to the uncorrelated sky map which was generated with a cut on at least three images per event in order to obtain a better angular resolution. The excess of HESS J1303-631 was fitted by a 2D elliptical function (two-dimensional Gaussian function with a σ for the Right Ascension and one for the Declination as well as a free rotation angle). Simultaneously, the PSR B1259-63/SS 2883 position was fitted by a 2D double Gaussian function $a \cdot \exp(\frac{\Delta \mathbf{r^2}}{2\sigma_1^2}) + b \cdot \exp(\frac{\Delta \mathbf{r^2}}{2\sigma_2^2})$ – describing a TeV point-source – to avoid a systematic influence on the fit by excess events from PSR B1259-63 leaking into the HESS J1303-631 region. The fit range covers a region of $2° \times 2°$ centered at the HESS J1303-631 position.

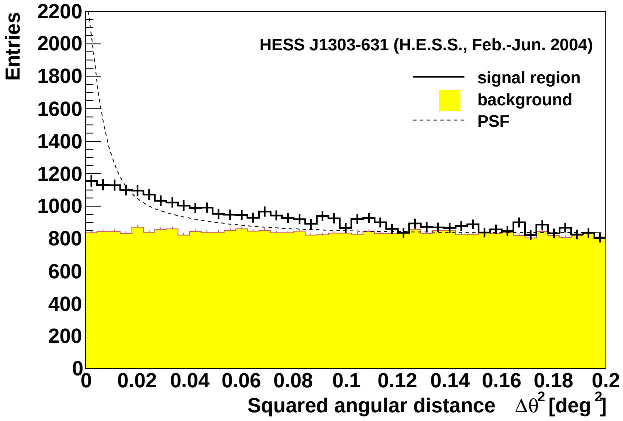

Figure 2: Distribution of ON-source events (solid histogram) and normalized OFF-source events (filled histogram) vs. the squared angular distance $\Delta\Theta^2$ between the reconstructed shower direction and the object position. The expected ON-distribution for a point-like source (H.E.S.S. point spread function, PSF) is indicated by the dashed line; it is normalized to give the same number of excess events as HESS J1303-631.

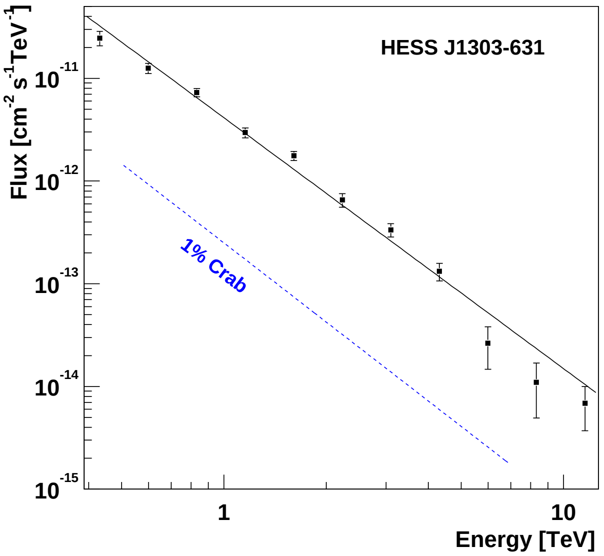

Figure 3: The differential energy spectrum of HESS J1303-631. The normalization was corrected for the source extension by multiplying with $f_{\rm corr} = 1.6 \pm 0.2$ (see text). A fit to the data with a power law (χ^2/d.o.f. $= 27/9$, solid line) is also shown. The power-law corresponding to a spectrum of 1 % of the Crab Nebula is also indicated (dashed line).

The χ^2/d.o.f. of the fit is 539/473. The contours of the function are shown in the right hand panel of Fig. 1. The position of HESS J1303-631 was found to be $\alpha = 13^{\rm h}03^{\rm m}0.4^{\rm s} \pm 4.4^{\rm s}$ and $\delta = -63^\circ 11' 55'' \pm 31''$ (J2000.0). The length and width of the fitted ellipse are within errors the same and clearly larger than that expected for a point source (see below). Therefore, the HESS J1303-631 excess is compatible with an extended and rotationally symmetric structure. The position of PSR B1259-63/SS 2883 obtained from the same fit was found to be $\alpha_{1259} = 13^{\rm h}02^{\rm m}49.2^{\rm s} \pm 3.6^{\rm s}$ and $\delta_{1259} = -63^\circ 50' 2.44'' \pm 21.1''$ which is in good agreement with its nominal position of $\alpha_{1259,\rm nom} = 13^{\rm h}02^{\rm m}47.7^{\rm s}$ and $\delta_{1259,\rm nom} = -63^\circ 50' 8.8''$. The width of the PSR B1259-63/SS 2883 excess was found to be compatible with the width of a point-source [2]. Fixing the fit position of PSR B1259-63/SS 2883 to its nominal sky coordinates does not change the results for the HESS J1303-631 position and extension within statistics. The systematic pointing uncertainty of the H.E.S.S. telescopes is estimated to be $\sim 20''$ for Right Ascension and Declination.

The distribution of the number of events in squared angular distance $\Delta\Theta^2$ measured between the reconstructed shower direction and the derived HESS J1303-631 position is shown in Fig. 2. The point spread function (PSF) of the H.E.S.S. detector of TeV γ-rays is also shown (dotted line). It has been derived from Monte Carlo simulations and Crab Nebula data and can be described by a one-dimensional double Gaussian function $a \cdot \exp(\Delta\Theta^2/2\sigma_1^2) + b \cdot \exp(\Delta\Theta^2/2\sigma_2^2)$. A single Gaussian function describing the intrinsic source profile of HESS J1303-631 was folded with the PSF. The folded function was fitted to the excess distribution resulting in an intrinsic width of $\sigma_{\rm HESSJ1303} = (0.16 \pm 0.02)^\circ$ with a χ^2/d.o.f. $= 21/42$.

Adjusting the angular cut to the derived extension ($\Delta\Theta^2 \approx \Delta\Theta^2_{\rm pointsrc} + \sigma^2_{\rm HESSJ1303} \leq 0.05\,{\rm deg}^2$) one obtains for the HESS J1303-631 position 2469 ± 119 excess events corresponding to a significance of 21 standard deviations calculated following [11].

4.3. Energy spectrum and light curve

An energy spectrum was derived using the extended angular cut of $\Delta\Theta^2 \leq 0.05\,{\rm deg}^2$ in order to take into account the extended emission region of HESS J1303-631. The effective areas which were used for the flux normalization were obtained from Monte Carlo simulations of point-sources. Applying the $\Delta\Theta^2$ angular cut to extended sources leads to a different fraction of cut events as compared to the application of the same cut to a point-source. Therefore, a correction factor $f_{\rm corr}(\Delta\Theta^2, \sigma)$ was introduced. It depends on the applied $\Delta\Theta^2$ angular cut and the extension σ of an assumed intrinsic Gaussian source emission profile and describes the factor by which the flux is underestimated when using point-source Monte Carlos for the extended source. The correction factor for the extension of HESS J1303-631 was calculated to be $f_{\rm corr} = 1.6 \pm 0.2$ and it was applied to the spectrum

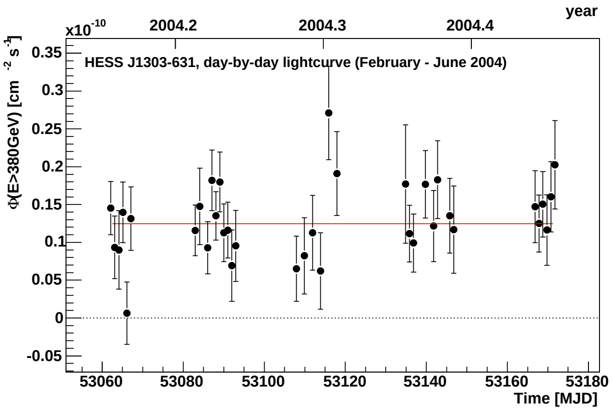

Figure 4: The HESS J1303-631 light curve covering February until June 2004. Shown is the integral flux $\Phi(E > 380\,\mathrm{GeV})$ vs. time in night-by-night bins. The fit of a constant function (solid line) results in a χ^2/d.o.f. of 35/35 being compatible with constant emission.

and the light curve. The systematic error on the correction factor which is dominated by the energy dependency of the TeV point spread function was estimated to be $< 10\,\%$ between 100 GeV and 10 TeV.

The spectrum is shown in Fig. 3. It was fitted by a power-law $\mathrm{d}N/\mathrm{d}E = N_0 \cdot (E/1\,\mathrm{TeV})^{-\Gamma}$ with a resulting photon index of $\Gamma = 2.44 \pm 0.05_{\mathrm{stat}} \pm 0.2_{\mathrm{syst}}$ and a normalization of $N_0 = (4.3 \pm 0.3) \cdot 10^{-12}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{TeV}^{-1}$ with a χ^2/d.o.f. of 27/9. Other spectral shapes are under study. The integral flux above 380 GeV was calculated to be $\Phi(E > 380\,\mathrm{GeV}) = (1.2 \pm 0.2) \cdot 10^{-11}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ corresponding to $(17 \pm 3)\,\%$ of the flux of the Crab Nebula. Spectra obtained from the different tracking positions as well as from the different observation periods were found to be compatible within statistical errors. The systematic error on the flux dominated by atmospheric extinction variations and energy calibration of the detector was estimated to be in the order of $\sim 30\,\%$. Detailed studies on morphology and spatially-resolved energy spectra are underway.

A light curve of the integral flux $\Phi(E > 380\,\mathrm{TeV})$ was derived on a night-by-night basis and is shown in Fig. 4. The integral fluxes were calculated using the effective areas and an assumed power-law as obtained from the overall differential energy spectrum applied to the count rates for each night. A fit of a constant function results in a χ^2/d.o.f. of 35/35 and therefore indicates constant emission from HESS J1303-631 during February until June, 2004.

5. SUMMARY & CONCLUSION

A new unidentified TeV γ-ray source HESS J1303-631 was serendipitously discovered in a dataset which was initially taken on the binary system PSR B1259-63/SS 2883 which was also discovered at TeV energies. For the first time in TeV γ-ray astronomy, the detection and analysis of two sources within the same field of view is achieved, showing the potential of the new generation of ground-based experiments – such as H.E.S.S. – with the stereoscopic observation mode and its large field of view of $\sim 5°$.

HESS J1303-631 was found to be clearly extended with a σ of an assumed intrinsic Gaussian emission profile of $\sigma = (0.16 \pm 0.02)°$. The energy spectrum can be described by a power-law with a photon index of $\Gamma = 2.44 \pm 0.05_{\mathrm{stat}} \pm 0.2_{\mathrm{syst}}$. The integral flux above 380 GeV was found to remain on a constant level of $(17 \pm 3)\,\%$ of the flux from the Crab Nebula during the observations taken between February and June, 2004. Detailed studies on morphology and spatially-resolved energy spectra are underway.

Up to now, no counterpart at other wavelengths was identified. However, the location close to the galactic plane places HESS J1303-631 in the vicinity of a variety of possible objects which might be involved in the production mechanisms explaining the observed TeV γ-ray emission. HESS J1303-631 has to be considered as the second unidentified TeV source detected following TEV J2032+4130 discovered in the Cygnus region by HEGRA [13, 14]. H.E.S.S. thus further opens the door to a new class of (yet-unidentified) TeV γ-ray sources. To further investigate possible production mechanisms and to understand this new region of the non-thermal universe future multi-wavelength observations (especially in X-rays) are essential and partially already initiated. A discussion of possible TeV γ-ray production scenarios can be found in [12].

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