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Detection of an unidentified TeV γ-ray source HESS J1303-631 close to the galactic plane with the H.E.S.S. Cherenkov telescopes

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A new TeV γ-ray source named HESS J1303-631 has been serendipitously discovered in the field of view of the H.E.S.S. Cherenkov telescopes pointed towards the binary system PSR B1259-63/SS 2883. The data were taken between February and June 2004. Up to now, no counterpart at other wavelengths was found. HESS J1303-631 is extended and emits on a constant flux level. The detection and basic features of this new source are reported.

1. Introduction

Cherenkov telescopes of ground based γ-ray astronomy achieve a very high sensitivity. Due to the limited field of view the pointing of the telescopes has in general to be decided on the basis of observations at other wavelengths. However, the comparatively large field of view of instruments such as HEGRA ($4.3,^\circ$ full angle) and H.E.S.S. ($5,^\circ$ full angle) together with the stereoscopic observation mode allows nevertheless a scan of a part of the sky [2, 7] and in particular allows a search for unknown sources in the field of view of individual pointings. In this way the first unidentified TeV γ-ray source TEV J2032+4130 has been discovered by HEGRA [1, 3] in archival data and now, with the H.E.S.S. telescopes, the second unidentified source HESS J1303-631 was discovered, followed by more unidentified sources found in the H.E.S.S. galactic plane scan [7]. The H.E.S.S. telescopes have originally been directed to search for TeV γ-ray emission from the binary system PSR B1259-63/SS 2883 near periastron beginning in February 2004. This binary system has been detected at TeV energies [5, 9]. 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, named HESS J1303-631 (see Fig. 1). The detection and basic features of this new source are reported. For a detailed discussion on a search for possible counterparts in other wavelengths and discussion of possible TeV γ-ray production scenarios refer to [8].

2. The H.E.S.S. Cherenkov telescopes & Dataset

The H.E.S.S. (High Energy Stereoscopic System) collaboration operates an array of four imaging atmospheric Cherenkov telescopes (IACTs) optimised for an energy range of γ-rays between $100\,\mathrm{GeV}$ and several $10\,\mathrm{TeV}$ in Namiba ($23^\circ16'18''$ S, $16^\circ30'1''$ E, 1800 m a.s.l.). Each telescope has a $107\,\mathrm{m}^2$ tessellated mirror surface and is equipped with a 960 photomultiplier tube camera with a field of view diameter of $\sim 5^\circ$ [12]. The telescopes are operated in a coincident mode assuring that an event is always recorded by at least two of the four telescopes allowing for stereoscopic reconstruction of the shower parameters. More information about H.E.S.S. can be found in [13].

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 $42.7,^\circ$ yielding an energy threshold of $E_{\mathrm{thr}} = 380\,\mathrm{GeV}$. The

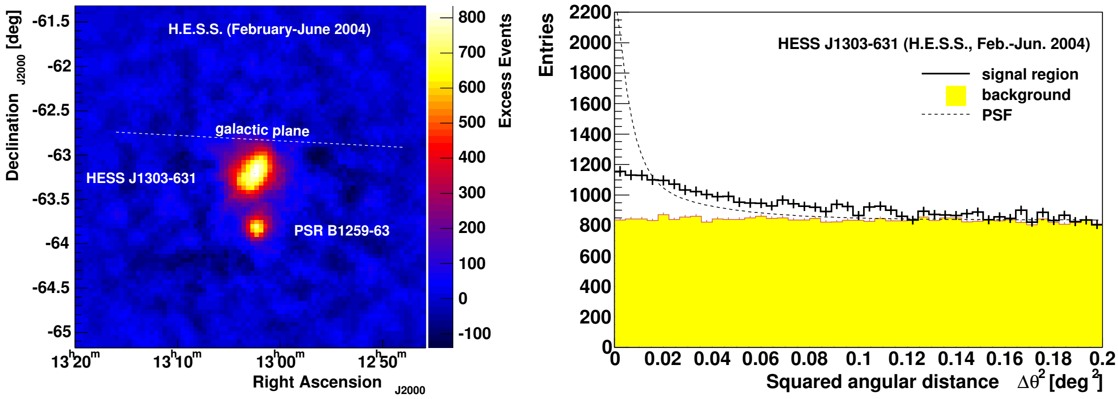

Figure 1. *Left:* The sky map showing both TeV γ-ray sources: HESS J1303-631 and PSR B1259-63/SS 2883. The Galactic plane is also indicated. The number of events are integrated within a circle of $\Theta \leq 0.14\,^\circ$ for each of the correlated bins. *Right:* Distribution of ON-source events (solid 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 (TeV point spread function, PSF) is indicated by the dashed line.

observations were performed in the *wobble* mode, tracking a position with an offset from 0.5 to $1.,^\circ$ in Declination or Right Ascension with respect to the nominal source position, allowing for an unbiased simultaneous background determination. 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. The raw data were subject to the standard calibration [4] and Hillas parameter-based analysis (see [6] for more details).

3. Analysis and Results

Shortly after the discovery of TeV γ-ray emission from 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 position of HESS J1303-631 was found to be $\alpha = 13^{\rm h}03^{\rm m}0^{\rm s}\!.4 \pm 4^{\rm s}\!.4$ and $\delta = -63,^\circ\,11'55'' \pm 31''$ (J2000.0). The excess is compatible with an extended and rotationally symmetric structure. 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. 1 right. For comparison the expectation for a point source is also shown (dotted line). 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 ($\Delta\Theta^2 \approx 0.05\,\rm deg^2$) one obtains for the HESS J1303-631 position an excess of 2469 ± 119 events corresponding to a significance of 21 standard deviations.

An energy spectrum was derived using the angular cut of $\Delta\Theta^2 = 0.05\,\rm deg^2$. To obtain the full flux integrated over the whole emission region of HESS J1303-631 the flux normalisation was corrected for the derived source extension (assuming an intrinsic Gaussian emission profile). Since this correction depends on the exact – and possibly energy dependent – shape of the source, it introduces a systematic error. Together with the effects of

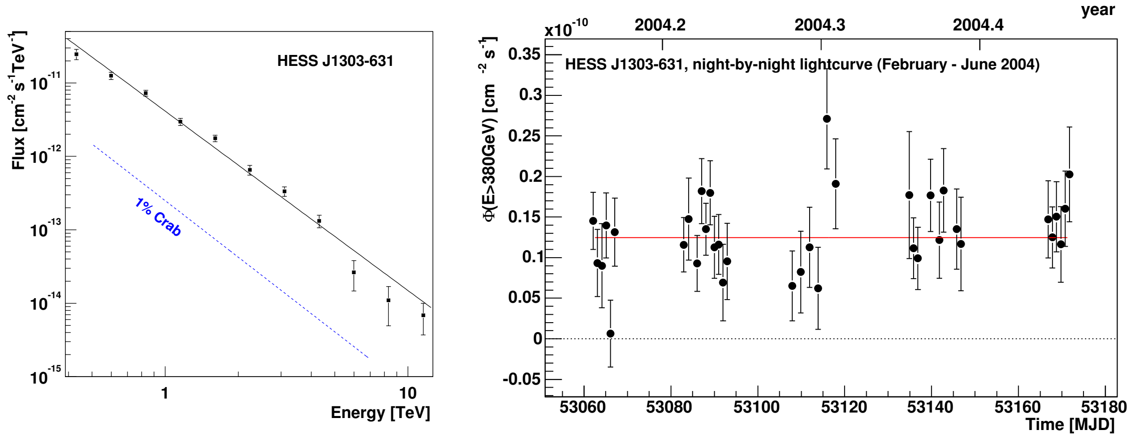

Figure 2. *Left:* The differential energy spectrum of HESS J1303-631. A fit to the data with a power law (solid line) is shown. The power-law corresponding to a spectrum of $1\,\%$ of the Crab Nebula is also indicated (dashed line). *Right:*The HESS J1303-631 light curve covering February until June, 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.

atmospheric extinction variations and energy calibration of the detector the systematic error on the flux was estimated to be in the order of $\sim 30\,\%$. The spectrum is shown in the left-hand panel of Fig. 2. 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 $N_0 = (4.3 \pm 0.3_{\mathrm{stat}}) \cdot 10^{-12}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{TeV}^{-1}$ with a χ^2/d.o.f. of $27/9$. The integral flux above $380\,\mathrm{GeV}$ was calculated to be $\Phi(E > 380\,\mathrm{GeV}) = (1.2 \pm 0.2_{\mathrm{stat}}) \cdot 10^{-11}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ corresponding to $(17 \pm 3)\,\%$ of the flux of the Crab Nebula. A light curve of the integral flux $\Phi(E > 380\,\mathrm{GeV})$ was derived on a night-by-night basis and is shown in the right panel of Fig. 2. To obtain the integral flux, the count rates for each night were corrected using the effective areas and an assumed power-law as obtained from the overall differential energy spectrum. A fit of a constant function to the light curve 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.

4. Search for possible counterparts

An extensive search for counterparts in other wavelengths has been carried out (for details refer to [8]). Up to now, no counterpart 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. A pulsar wind nebula powered by the nearby pulsar PSR J1301-6305 is one of the interesting candidates. Another possibility would be the Cen OB1 stellar association which provides enough kinetic energy by stellar winds. The interaction of an expanding supernova remnant shell with a molecular cloud as target material can also be seen as an interesting configuration for TeV γ-ray production. Three molecular clouds are located along the line of sight of HESS J1303-631: The Coalsack nebula at a distance of ~ 175 pc, a cloud in the Carina-Sagittarius arm at $2.1\,\mathrm{kpc}$, resp. $7.7\,\mathrm{kpc}$, and the giant molecular cloud GMC G303.0-0.4 in the Carina Arm at a distance of $12\,\mathrm{kpc}$. Finally, the possibility of a clump of annihilating dark matter particles was considered, assuming a NFW profile for the density distribution [11]. This however can be excluded since the luminal profile of HESS J1303-631 is not reproduced.

5. Summary & Conclusions

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. The binary system was also discovered at TeV energies [5]. For the first time in TeV γ-ray astronomy, the detection and analysis of two sources within the same field of view is achieved which subsequently also occured in other pointings towards the galactic plane, 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 $\sim 5,^{\circ}$.

HESS J1303-631 was found to be clearly extended with a width of an assumed intrinsic Gaussian emission profile of $\sigma = (0.16 \pm 0.02)\,^{\circ}$. The energy spectrum can be described by a power-law with a photon index of $\Gamma = 2.44 \pm 0.05_{\rm stat} \pm 0.2_{\rm syst}$. The integral flux above $380\,\mathrm{GeV}$ 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.

A search for counterparts in other wavelengths had been carried out and no clear counterpart was identified. Therefore 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 [1, 3]. Meanwhile, the results of the H.E.S.S. galactic plane scan revealed more unidentified TeV γ-ray sources [7], thus further opening 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 [10].

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