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H.E.S.S.: Variable VHE γ-Ray Emission from the Binary Pulsar PSR B1259−63

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We report on the detection of very high energy (VHE) γ-ray emission from the binary system PSR B1259−63 / SS 2883 of a radio pulsar orbiting a massive, luminous Be star in a highly eccentric orbit. The observations around the 2004 periastron passage of the pulsar were performed with the four 13 m Cherenkov telescopes of the H.E.S.S. experiment. Between February and June 2004, a γ-ray signal from the binary system was detected with a total significance above $13\,\sigma$. The flux was found to vary significantly on timescales of days, making PSR B1259−63 the first variable galactic source of VHE γ-rays observed so far. Strong emission signals were observed in pre- and post-periastron phases with a flux minimum around periastron, followed by a gradual flux decrease in the months after. The measured time-averaged energy spectrum above a mean threshold energy of 380 GeV can be fit by a simple power law $\propto E^{-\Gamma}$ with a photon index $\Gamma = 2.7 \pm 0.2_{\rm stat} \pm 0.2_{\rm sys}$ and flux level of $\sim 5\%$ of the flux of the Crab nebula.

1. Introduction

PSR B1259−63 / SS 2883 is a binary system consisting of a ∼48 ms pulsar in orbit around a massive Be companion star [1]. The highly eccentric orbit of the pulsar places it just $26R_* \sim 10^{13}$ cm from the companion, with radius R_*, during periastron every ∼3.4 yrs. This makes PSR B1259−63 a unique laboratory for the study of pulsar winds interacting with a changing environment in the presence of an extremely intense photon field.

The ultra-relativistic pulsar wind is believed to accelerate electrons to multi-TeV energies before or after its termination. The *ROSAT* and *ASCA* satellites [2, 3] detected unpulsed non-thermal X-rays extending up to soft γ-rays [4] which likely originate from the synchrotron emission of these electrons. High energy γ-rays can be produced by the interaction of the intense photon field of the companion star with the accelerated electrons through Inverse Compton (IC) scattering [5]. Observations in optical and radio wavelengths indicated that the companion has a dense equatorial disc, a common feature among Be stars. The disc is likely to be inclined with respect to the orbital plane [6, 7], a unique characteristic of the system. The pulsed radio emission of the pulsar was found to be eclipsed [8] near the periastron passage (at time τ). Simultaneously, continuous radio emission was detected, with two high flux states around $\sim \tau - 10$ and $\sim \tau + 20$ days when the pulsar is thought to cross the disc, and remaining detectable beyond $\tau + 100$ days. In addition to enhanced IC γ-ray production during this phase, one might therefore expect an additional component of γ-radiation associated with interactions of accelerated electrons and possibly hadrons with the dense ambient gas of the disc [9].

2. Observations

Observations of PSR B1259−63 between February and June 2004 were performed with the High Energy Stereoscopic System (H.E.S.S.), consisting of four imaging atmospheric Cherenkov telescopes [10, 11, 12,

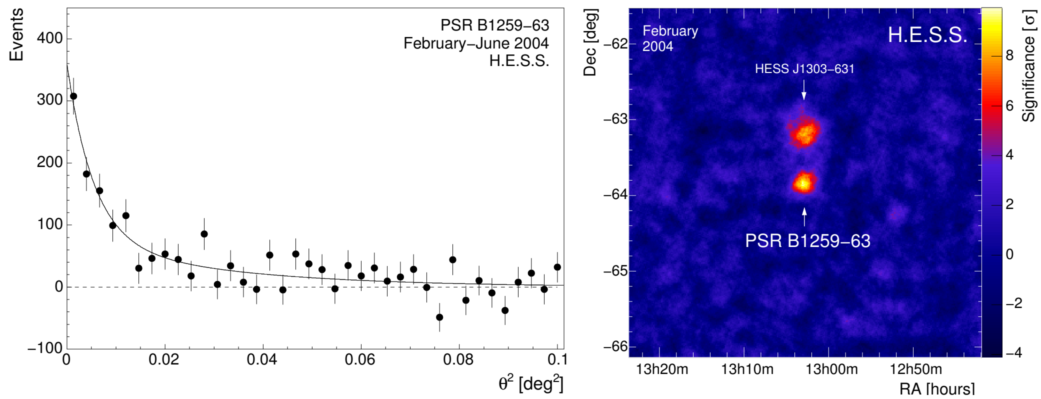

Figure 1. *Left*: Distribution of background-subtracted γ-ray candidates in θ^2, where θ is the angular distance between the reconstructed shower direction and the pulsar position, for the complete 2004 data set. The solid line indicates the distribution expected for a point source of γ-rays. *Right*: Significance sky-map (correlated bins) of the H.E.S.S. field of view centered on the position of PSR B1259−63 for the pre-periastron phase (February 2004, 7.9 h live time). The excess $\sim 0.6°$ north of the pulsar is the newly discovered unidentified TeV source HESS J1303−631.

13, 14] operated in coincidence and located in Namibia, at $23°16'$ S $16°30'$ E at 1800 m a.s.l. All observations were carried out on moonless nights tracking sky positions with an alternating offset of $\pm 0.5°$ in declination relative to the source (the so-called *wobble* mode). This allows the determination of the background from the same field of view and omit off-source observations, effectively doubling the observation time.

The data set, selected according to standard quality criteria, has a dead-time corrected exposure (live-time) of 48.6 h and a mean zenith angle of 42.7°. The corresponding mean threshold energy defined by the peak of the γ-ray detection rate for a Crab-like spectrum after selection cuts was estimated to be 380 GeV. Recorded air showers were reconstructed by parameterising each telescope image by its centre of gravity and second moments followed by the stereoscopic reconstruction of the shower geometry, providing an angular resolution of $\sim 0.1°$ for individual γ rays. The γ-ray energy was reconstructed with a typical resolution of $\sim 15\%$ by comparing the image intensity and shower geometry with Monte Carlo simulated γ-ray showers. The γ-ray candidates were selected using cuts on image shape, optimised on simulations. A more detailed description of the analysis techniques can be found in [15].

3. Results

Figure 1 (left) shows the distribution of the squared angular distance θ^2 of excess events relative to the position of PSR B1259−63 for the whole data set. The clear excess of 955 ± 69 events in the direction of the pulsar has a significance of 13.8 σ and is consistent with a distribution obtained from a simulated γ-ray point source. The background was estimated from several non-overlapping control regions with the same distance to the centre of the field of view [16]. A 2D-analysis of the H.E.S.S. field of view around PSR B1259−63 (see Fig. 1, right) revealed a new unidentified VHE γ-ray source HESS J1303−631 [17, 18]. The resulting bias in the background estimation was corrected in the analysis. The background for each position in the field of view was estimated from a ring around this position, correcting for the radial acceptance of the instrument within the field of view, and avoiding contamination from the γ-ray sources by selecting appropriate background regions.

The time averaged energy spectrum for the complete data set is shown in Fig. 2. A power-law fit to the

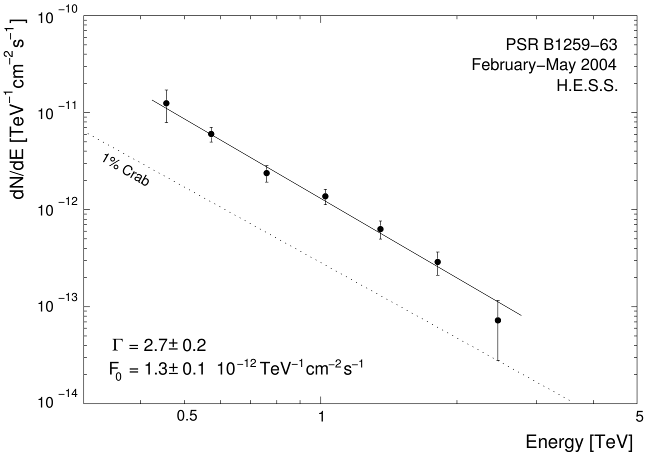

Figure 2. Energy spectrum dN/dE of γ-rays from PSR B1259−63 determined from the H.E.S.S. 2004 data. The solid line indicates the power-law fit $F(E) = F_0 E_{\mathrm{TeV}}^{-\Gamma}$.

differential energy spectrum $F(E) = F_0 E_{\mathrm{TeV}}^{-\Gamma}$ yields a photon index $\Gamma = 2.7 \pm 0.2_{\mathrm{stat}} \pm 0.2_{\mathrm{sys}}$, $F_0 = (1.3 \pm 0.1_{\mathrm{stat}} \pm 0.3_{\mathrm{sys}}) \cdot 10^{-12}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{TeV}^{-1}$, and a χ^2 of 2.3 with 5 degrees of freedom. The integral flux above the mean threshold energy is equivalent to 4.9% of the Crab Nebula flux [19] above this threshold.

The light curve of the energy flux above 1 TeV is shown in Fig. 3. The data clearly indicate a variable flux. This can be quantified by a fit of a constant flux to the data, yielding a χ^2 of 90.9 with 35 degrees of freedom. Unfortunately, the periastron passage is not covered by our data due to the full moon, but it is apparent that a low flux state after periastron is followed by a distinct rise beginning at $\tau \sim +15$ days and a slow decrease until $\tau \sim +75$ days where the excess observed is no longer significant.

4. Conclusions

The detection of VHE γ-ray emission from the binary system PSR B1259−63 / SS 2883 by H.E.S.S. provides the first model-independent evidence of particle acceleration to multi TeV energies in this object. The measured spectral shape of the emission is compatible with that expected to result from IC scattering of electrons, accelerated in the pulsar wind termination shock, and the thermal photons of the companion star. In this case,

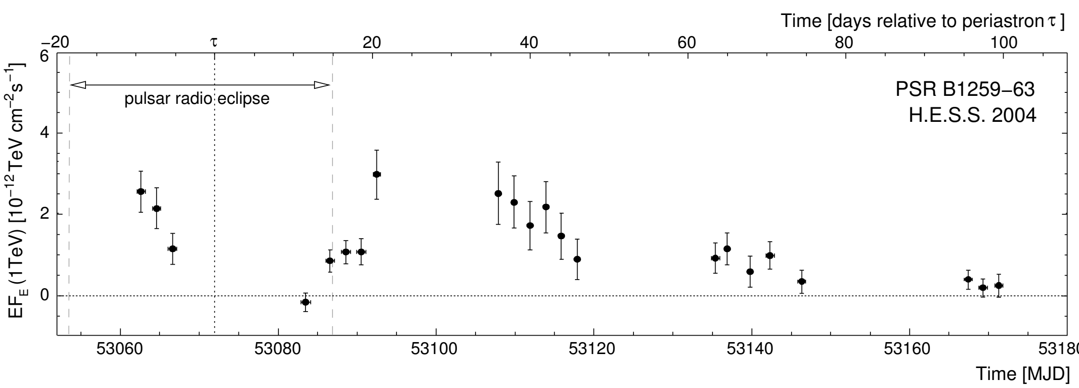

Figure 3. VHE γ-ray light curve of PSR B1259−63 around its 2004 periastron passage (dotted vertical line) showing the integral energy flux above 1 TeV averaged over a period of 2 days as measured by H.E.S.S.

a numerical evaluation of the IC scattering in the Klein-Nishina regime showed that the energy of the radiating electrons follows a distribution $\propto E^{-2.2}$, suggesting that these electrons primarily loose energy by adiabatic expansion after their acceleration in the pulsar wind termination shock. In combination with coeval observations of the X-ray synchrotron emission by the *RXTE* and *INTEGRAL* instruments [20], and assuming that these X-rays are produced by the same population of electrons which are responsible for the observed γ-ray emission, the magnetic field strength within the radiating plasma was estimated to be of the order of 1 G. The observed variability pattern of the γ-ray flux suggests that the interaction of the pulsar wind with the stellar disc plays an important role in the γ-ray production mechanism. The flux variation might be explainable by a varying spatial confinement of the accelerated pulsar wind particles by the kinetic and thermal pressure of the stellar mass outflow.

A more detailed analysis and discussion of the results is presented elsewhere [21].

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