Observations of SNR RX J1713.7-3946 with H.E.S.S.

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Abstract.
The shell-type supernova remnant (SNR) RX J1713.7–3946 (G347.3-0.5) was discovered with ROSAT [1] in X-rays and later claimed as source of TeV γ-rays [2, 3]. This object, together with several other southern hemisphere SNRs, is a prime target for observations with the High Energy Stereoscopic System (H.E.S.S.), a new system of imaging atmospheric Cherenkov telescopes which was completed at the end of 2003 in Namibia and is now in full operation [4, 5, 6]. Here we report on observations of the SNR RX J1713.7–3946 which have been performed during the construction and commissioning of the H.E.S.S. system (data originally published here [7]). We confirm TeV emission from this source and present the first ever γ-ray image of an astronomical object resolved on arc minute scales. This image shows shell morphology similar to that seen in X-rays, however at photon energies some nine orders of magnitude higher. The characteristics of the energy spectrum imply efficient acceleration of charged particles to energies beyond 100 TeV, consistent with current ideas of particle acceleration in young SNR shocks.

INTRODUCTION

H.E.S.S. (the name is also tribute to V. F. Hess, the discoverer of cosmic rays) exploits the most effective detection technique for very-high-energy γ-rays, namely, the imaging of Cherenkov light from air showers. This technique, which was pioneered by the Whipple collaboration [8], is almost the only form of observational high-energy astronomy which does not require the use of space instruments. Its key advantage is that the effective collection area (determined by the opening angle of the Cherenkov light cone and the height of the cascade in the atmosphere) is of order 10^5 m^2, which is far larger than that available to any currently conceivable space mission. Combined with the approach of stereoscopic imaging of the air showers using a system of telescopes, as pioneered by the HEGRA collaboration [9], this yields a very powerful technique for imaging and obtaining energy spectra of astronomical sources at TeV energies.

H.E.S.S., which is such a stereoscopic system, consists of four 13 m diameter telescopes [10] spaced at the corners of a square of side length 120 m, each equipped with a 960 phototube camera [11] covering a field of view of diameter 5°. Construction of the telescope array started in 2001, the full array was completed in December 2003 with the comissioning of the fourth telescope. The complete system has an angular resolution of a few arc minutes, an effective energy range from 100 GeV to 10 TeV with energy resolution of 15–20% and a flux sensitivity approaching 10^{-13} erg cm^{-2} s^{-1}. These characteristics, together with its southern hemisphere location, make H.E.S.S. ideally suited for spectroscopic and morphological studies of Galactic plane sources such as RX J1713.7–3946, which is now the first SNR shell to be confirmed as source of TeV γ-rays. TeV emission has also been reported from the remnant of SN 1006 [12], which H.E.S.S. observations didn't confirm so far [13], and from Cassiopeia A [14, 15] (a classical core-collapse SNR and the weakest TeV source yet reported) which is situated in the northern hemisphere and thus inaccessible to H.E.S.S..

OBSERVATIONS OF RX J1713.7–3946 IN 2003

Here we present results derived from data taken between May and August 2003 during two phases of the construction and commissioning of the system. During the first phase, two telescopes were operated independently with stereoscopic event selection done offline using GPS time stamps to identify coincident events. During the second phase, also using two telescopes, coincident events were selected in hardware using an array level trigger. The total on-source observation time was 26h, after run selection and dead time correction a data set of 18.1 live hours was used in this analysis. At the trigger level (for the observation altitude angles of 60 to 75 degrees), the energy thresholds for the two configurations were 250 GeV (without the array level trigger) and 150 GeV (with the array level trigger). In this analysis hard cuts were used to select only well reconstructed showers. This primarily served to drastically reduce the number of background cosmic-ray events, but it also homogenised these data taken with two different hardware configurations and it improved the angular resolution. Thus, systematic errors are greatly reduced at the expense of a higher energy threshold of $\sim$ 800 GeV for the combined data set.

Fig1 shows the resulting count map centred on RX J1713.7–3946. The SNR stands out clearly from the residual charged cosmic-ray background with a significance of 20 standard deviations. Shell structure is visible and coincides closely with that seen in X-rays, as illustrated in Fig2. We note that this is the first case where the identification of an active, that is accelerating, celestial γ-ray source (as opposed to a passive cloud or density enhancement, merely penetrated by energetic particles which are accelerated elsewhere) can be based, not just on a positional coincidence, but on the image morphology. The overall flux above 1 TeV is $(1.46 \pm 0.17\,(\mathrm{statistical}) \pm 0.37\,(\mathrm{systematic})) \times 10^{-7}$ photons m^{-2} s^{-1} which corresponds to about 66% of the Crab flux as measured by H.E.S.S.. The mean γ-ray brightnesses from the regions marked in Fig1 are in the ration $1:1.4:1:1.2$ $(N:W:SE:I)$. More elaborate analyses of these data using different background models (required for the determination of the spectrum) and independent (and different) analysis chains confirm the results presented here.

The energy spectrum of the whole remnant is shown in Fig3. It appears rather hard, the data are well described by a power law with a photon index $\Gamma = 2.19 \pm 0.09 \pm 0.15$, as compared to the photon index of $\Gamma = 2.84 \pm 0.15 \pm 0.20$ reported by the CANGAROO-

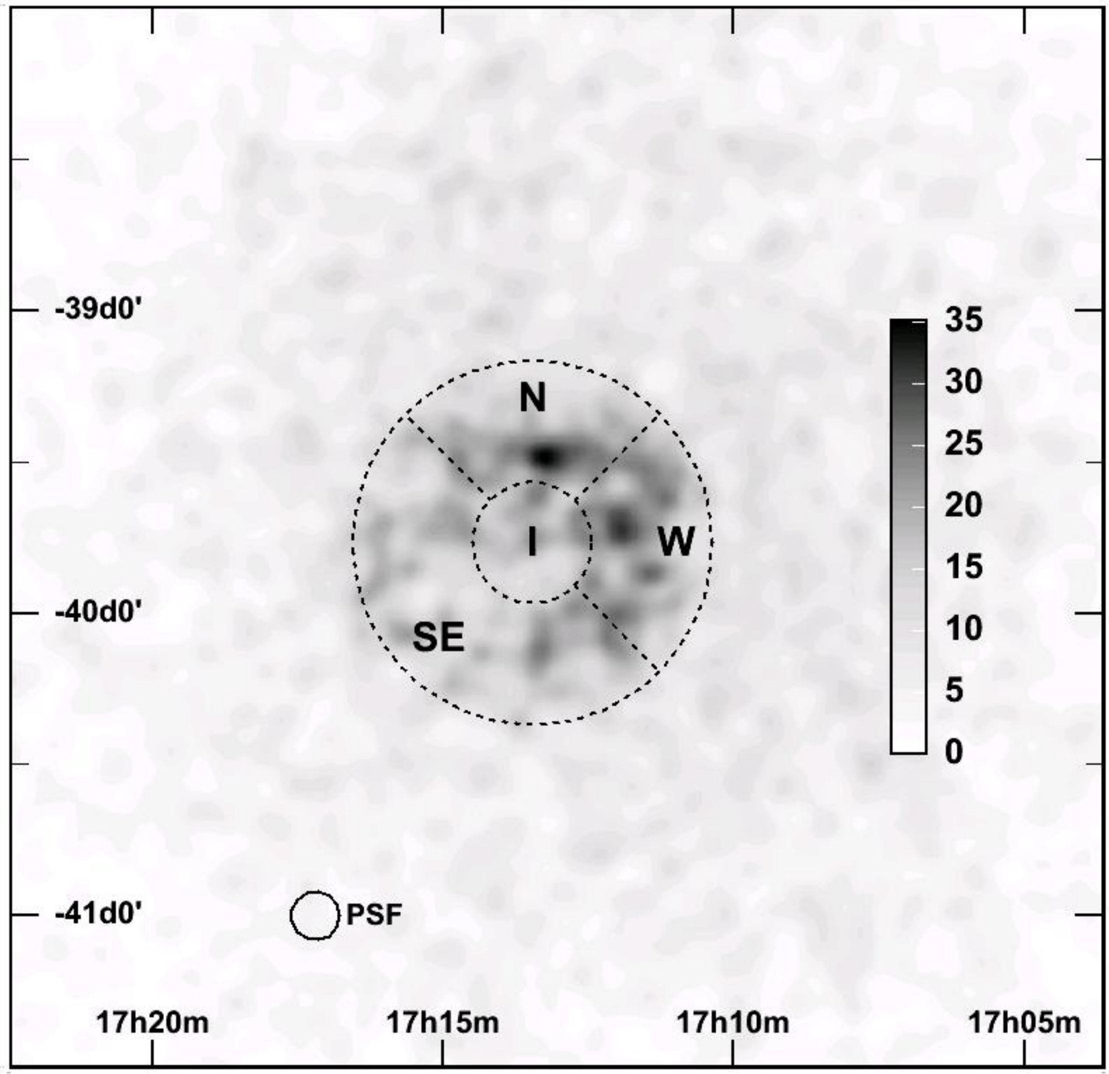

FIGURE 1. γ-ray count map around the SNR RX J1713.7–3946. The integrated fluxes above 1 TeV from the regions indicated by the dashed black lines are: $(3.0 \pm 0.6) \times 10^{-8}$ photons m^{-2} s^{-1} from the northern (N) rim, $(4.1 \pm 0.8) \times 10^{-8}$ photons m^{-2} s^{-1} from the western (W) rim, $(5.9 \pm 1.0) \times 10^{-8}$ photons m^{-2} s^{-1} from the southeastern (SE) rim, and $(1.7 \pm 0.6) \times 10^{-8}$ photons m^{-2} s^{-1} from the interior (I). The mean γ-ray brightnesses from these regions are in the ration $1:1.4:1:1.2$ $(N:W:SE:I)$. The 70% containment radius of the γ-ray point-spread function (PSF) for this particular data set is indicated in the bottom left-hand corner. Any structure smaller than that circle should not be considered as real since they are beyond the angular resolution of the instrument. The map itself is smoothed with a Gaussian of standard deviation 3 arc minutes. The linear grey scale is in units of counts, the axes are in units of right ascension (horizontal axis) and declination (vertical axis).

II collaboration for the northwest part of the SNR [3]. The integral energy flux between 1 TeV and 10 TeV is estimated to be 3.5×10^{-11} erg cm^{-2} s^{-1}, which is an order of magnitude smaller than the non-thermal X-ray flux.

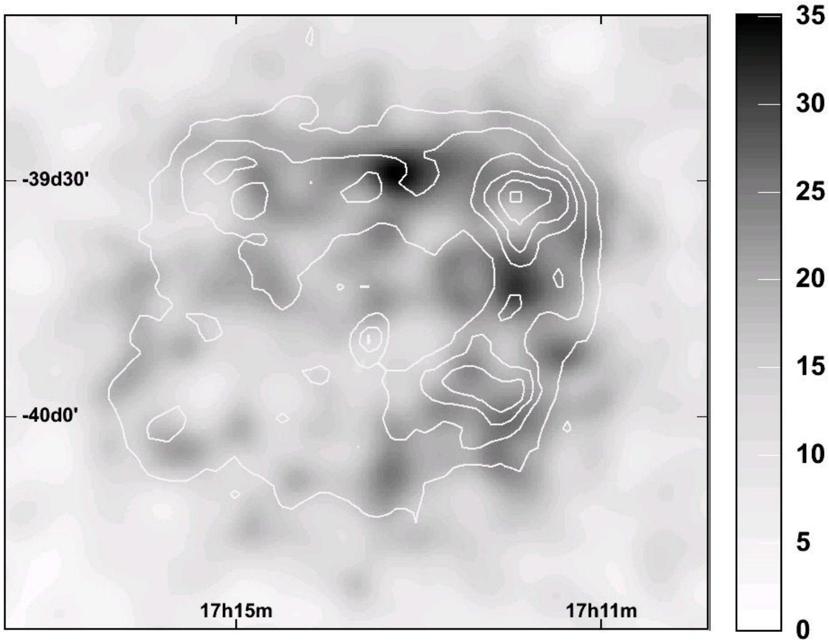

FIGURE 2. γ-ray image of the SNR RX J1713.7–3946 obtained with the H.E.S.S. telescopes. It represents the first ever astronomical image in the TeV energy regime. As in Fig1 the image is smoothed with a Gaussian of standard deviation 3 arc minutes matched to the angular resolution of the instrument for this particular data set. The linear grey scale is in units of counts. The SNR stands out from the background in the field of view which is at a level of about five counts. The fact that RX J1713.7–3946 is visible in the raw post-cuts data demonstrates impressively that the structures seen are real and not artefacts of the analysis. This image, obtained with a partial array during the construction of the experiment, demonstrates the ability of H.E.S.S. to map extended objects. The superimposed, linearly spaced white contour lines show the X-ray surface brightness of RX J1713.7–3946 as seen by ASCA in the $1-3$ keV energy band [16]. Note that the angular resolution of ASCA is comparable to that of H.E.S.S. enabling direct comparisons of the two measurements.

CONCLUSIONS

RX J1713.7–3946 is one of the brightest Galactic X-ray SNR known [17], with a flux density of a few times 10^{-10} erg cm^{-2} s^{-1}. In X-rays it reveals typical shell morphology, but remarkably the X-ray spectrum is completely dominated by a non-thermal continuum with no detectable line emission. The most plausible origin of these X-rays is the synchrotron radiation of 100-TeV electrons [18, 19]. However, since alternative explanations are not absolutely ruled out [20], only the detection of TeV emission from this SNR presented here provides unambiguous evidence for the acceleration of particles to multi-TeV energies. Furthermore, the H.E.S.S. data, which revealed shell structure of RX J1713.7–3946, represent the first resolved γ-ray image of an astronomical source. New data taken in 2004 with the full H.E.S.S. array is currently under investigation. The increased sensitivity (four instead of two telescopes) will enable spatially resolved spectral studies.

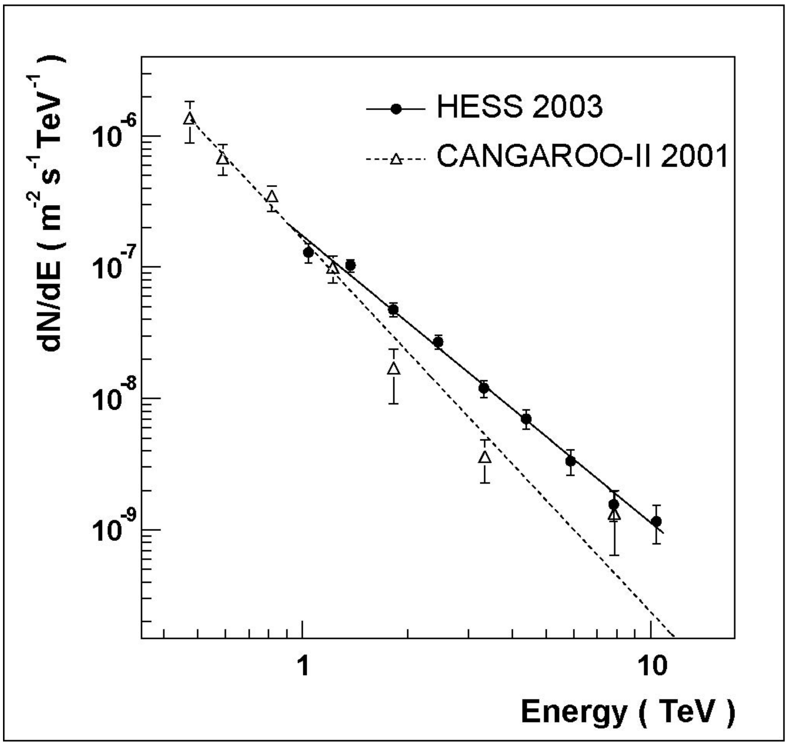

FIGURE 3. γ-ray energy spectrum of RX J1713.7–3946 as measured by H.E.S.S.. These data (indicated as solid circles) can be described by a power law, $dN/dE \propto E^{-\Gamma}$, the best fit result (solid line) is $\Gamma = 2.19 \pm 0.09\,(\text{statistical}) \pm 0.15\,(\text{systematic})$ with $\chi^2 = 5.9$ with 7 degrees of freedom. The integral flux of the whole SNR above 1 TeV is $(1.46 \pm 0.17\,(\text{statistical}) \pm 0.37\,(\text{systematic})) \times 10^{-7}$ photons $\text{m}^{-2}\,\text{s}^{-1}$. There is no evidence for a cut-off in the data, but if one nevertheless fits an exponentially cut-off power law spectrum of the form $dN/dE \propto E^{-\Gamma_c} e^{-E/E_c}$, the minimum acceptable value of E_c is 4 TeV with a very hard photon index of $\Gamma_c = 1.5$. The spectrum measured by CANGAROO-II [3] for the northwestern part of the remnant is shown as open triangles, the best fit result as dashed line. It should be noted though that CANGAROO-II reported a spectrum only for a part of the SNR which prohibits a direct comparison of the two measurements.

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