Observations of the Shell-Type Supernova Remnants RX J1713.7−3946 and RX J0852.0−4622 (Vela Junior) with H.E.S.S.

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We report on the detection of the shell-type supernova remnants (SNRs) RX J1713.7−3946 and RX J0852.0−4622 by H.E.S.S. in observations made in 2003 and 2004. Both sources are found to be clearly extended with morphologies correlated with those from X-ray observations. RX J1713.7−3946 and RX J0852.0−4622 are thus the first SNRs ever resolved in TeV γ-rays. The energy spectra are relatively hard (photon index ~ 2.2) and the integral flux is at the level of 66% and 100% for RX J1713.7−3946 and RX J0852.0−4622, respectively.

1. Introduction

Supernova remnants (SNRs) with non-thermal X-ray emission are prime candidates for accelerating cosmic rays up to very high energies, and their observation in VHE γ-rays is expected to provide insight into the underlying acceleration mechanisms. So far, only one of these SNRs, RX J1713.7−3946, was detected by two independent experiments, CANGAROO [Muraishi et al. 2000, Enomoto et al. 2002] and H.E.S.S.[Aharonian et al. 2004], employing the imaging atmospheric Cherenkov technique.

Here we present recent data on RX J1713.7−3946 and RX J0852.0−4622 obtained with H.E.S.S. in 2003 and 2004. Both SNRs are relatively young and show only weak radio emission. The X-ray emission is dominated by a non-thermal continuum interpreted as being the synchrotron radiation of multi-TeV electrons in the SNRs magnetic field. The TeV γ-ray emission of both remnants is found to be clearly extended. RX J1713.7−3946 and RX J0852.0−4622 are thus the first SNRs ever resolved in TeV γ-rays.

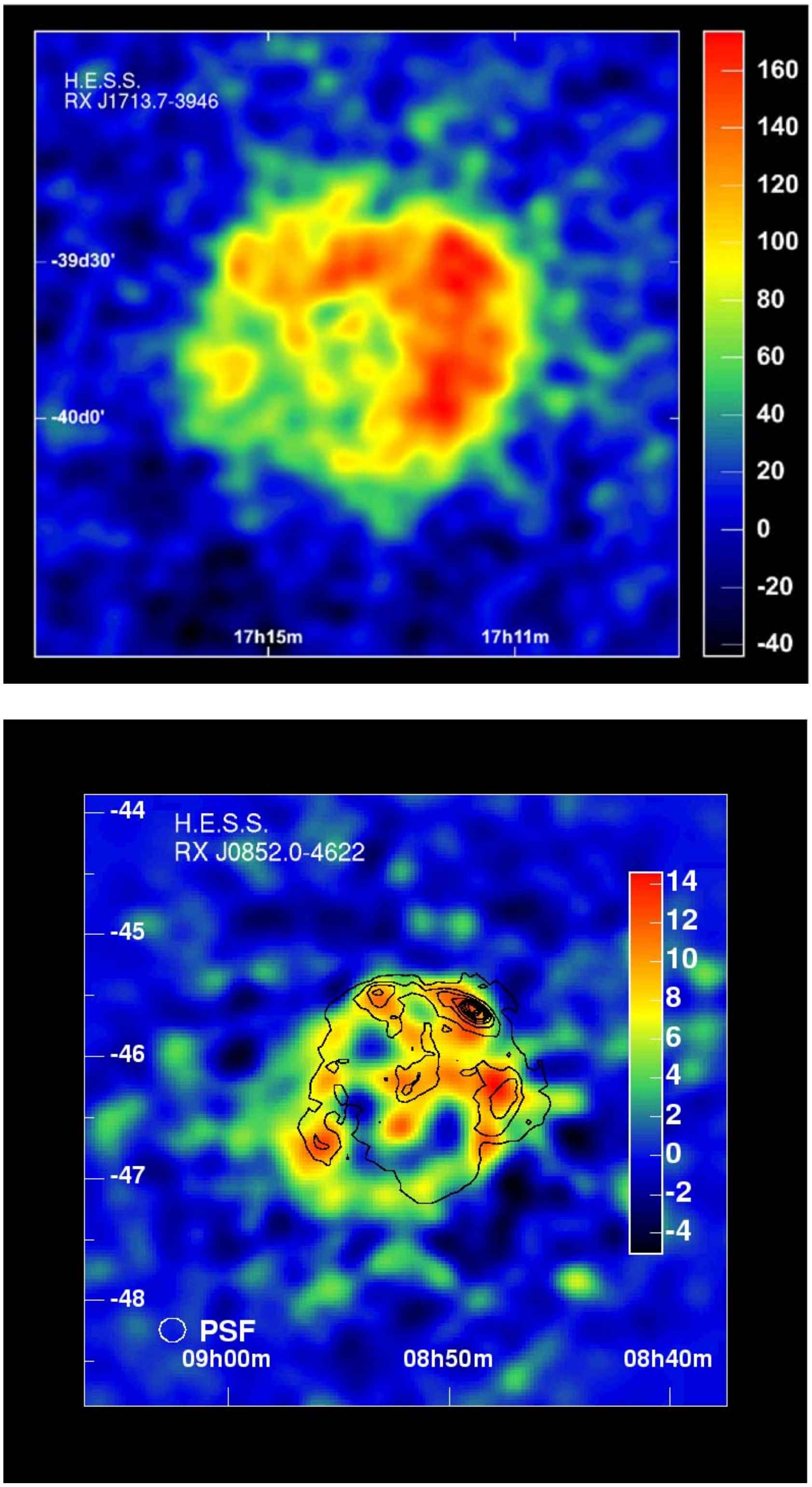
2. The H.E.S.S. Detector

H.E.S.S. (High Energy Stereoscopic System) is an array of four imaging Cherenkov telescopes dedicated to the detection of VHE γ-rays with energies above 100 GeV [Benbow 2004]. Each telescope has a tessellated mirror with an area of $107\,\mathrm{m}^2$ [Bernlöhr et al. 2003, Cornils et al. 2003] and a camera consisting of 960 photomultiplier tubes [Vincent et al. 2003]. The H.E.S.S. array can detect point sources at flux levels of about 1% of the Crab nebula flux with a significance of $5\,\sigma$ in 25 h of observation [Benbow 2004]. H.E.S.S. is currently the most sensitive instrument to observe VHE γ-ray sources. With its angular resolution of better than 0.1° per event and its large field of view (5°) it is additionally in an ideal position to unravel the γ-ray morphology of extended sources.

3. Analysis Technique

The data were recorded in runs of typical 28 min duration. A trigger required the simultaneous observation of an air shower by at least two telescopes [Funk et al. 2004]. A run quality selection based on weather conditions and system monitoring was applied and only runs of good quality were used for analysis. The data were calibrated using the technique described in [Aharonian et al. 2004]. After the image cleaning, shower directions were reconstructed using shower images in different cameras. In order to reject the cosmic ray background, cuts on scaled image parameters were applied. These cuts were optimised on Monte Carlo simulations for point-like sources on the level of 10% of the Crab flux. The γ-ray energy was determined from the image intensity and shower geometry with a typical resolution of $\sim$15%. The cosmic-ray background was estimated from observations of sky regions where no γ-ray sources are known (off-source runs). A detailed description of the analysis technique is given in [Aharonian et al. 2005].

An independent analysis [Lemoine-Goumard and de Naurois 2004] was carried out and confirmed the presented results.



a) RX J1713.7−3946. These data, taken in 2004 with the full H.E.S.S. array, confirm the measurements reported previously [Aharonian et al. 2004].

b) RX J0852.0−4622. The overlaid contour is the X-ray measurement of ASCA in the energy range between 0.7 and 10 keV [Slane et al. 2001]. γ-ray and X-ray counts are found to be well correlated.

Figure 1: **Sky excess maps of both supernova remnants.** The maps are smoothed with a Gaussian matched to the angular resolution of the instrument (PSF). Features smaller than the PSF should not be considered as real. The PSF is indicated by a white circle. The results were cross-checked using a different analysis technique. Axes are right ascension (hh:mm), declination (degrees) and excess photon counts.

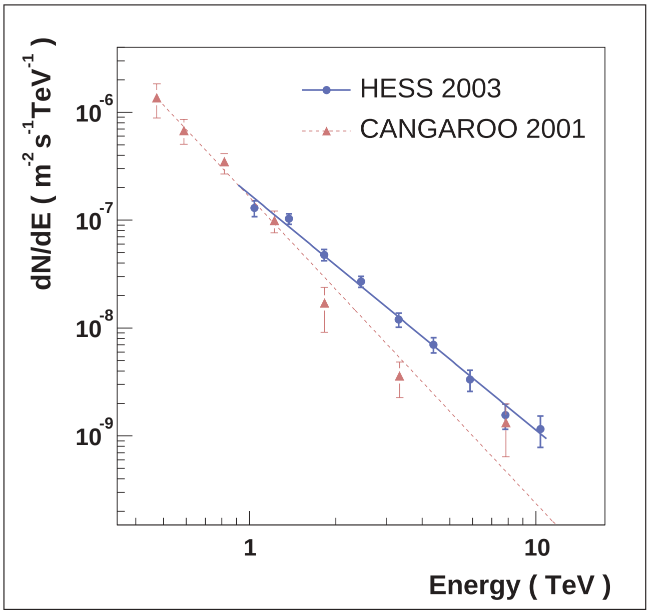


Figure 2: **Differential energy spectrum of RX J1713.7−3946.** Shown are the H.E.S.S. 2003 data (blue) and the CANGAROO 2001 data (red). The results of power-law fits are indicated by the lines.

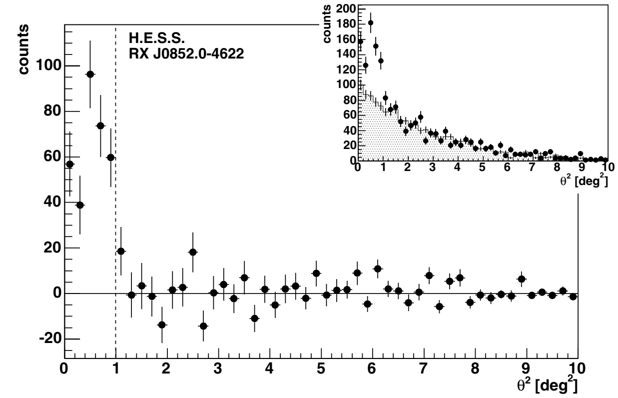


Figure 3: **Radial Excess of γ-rays from RX J0852.0−4622.** The angle θ is the angular distance between the centre of the SNR and the direction of the γ-ray. The inset shows the distribution of on-source events (data points) and the live-time-normalised background (histogram).

4. RX J1713.7−3946 (G347.3−0.5)

The shell-type supernova remnant RX J1713.7−3946 is situated in the Galactic plane, in the constellation Scorpius. It was discovered in X-rays with ROSAT [Pfeffermann and Aschenbach 1996] and later claimed as source of TeV γ-rays [Muraishi et al. 2000, Enomoto et al. 2002]. In X-rays, it exhibits a typical shell morphology, but remarkably the X-ray spectrum is completely dominated by a non-thermal continuum with no detectable line emission. The energy flux is a few times 10^{-10} erg cm^{-2}s^{-1} [Slane et al. 1999].

In 2003, during construction and commissioning of the H.E.S.S. telescope system, observations of the SNR RX J1713.7−3946 were performed. The data represented the first ever resolved TeV γ-ray image of an astronomical object [Aharonian et al. 2004]. The image shown in Fig. 1a), from the 2004 data set taken with the full H.E.S.S. array, confirms the previous measurement. The shell of the remnant is clearly resolved and the overall morphology is similar to that seen in X-rays. The energy spectrum of the whole remnant, which is shown in Fig. 2, appears rather hard, the data are well described by a power-law with a photon index of 2.2. The extension of the γ-ray spectrum to energies of 10 TeV and beyond implies efficient acceleration of charged particles to energies of 100 TeV and beyond, consistent with current ideas of particle acceleration in young SNR shocks.

5. RX J0852.0−4622 (Vela Junior)

RX J0852.0−4622 is a shell-type SNR with a diameter of $\sim 2°$ located in the line of sight to the Vela SNR. The X-ray emission is clearly non-thermal [Slane et al. 2001, Aschenbach 1998, Iyudin et al. 2005]. The CANGAROO collaboration reported γ-ray emission from the north-western part of the shell [Katagiri et al. 2005]. The distance to RX J0852.0−4622 is still under discussion. The remnant might be as close as 200 pc (680 years old) [Aschenbach et al. 1999] or as far as 1–2 kpc [Slane et al. 2001].

H.E.S.S. has observed RX J0852.0−4622 in February 2004 with the full 4-telescope system. Data with an overall dead-time corrected live time of 3.2 h taken at zenith angles between 22° and 30° (mean: 25°) were recorded. In order to reduce the number of background cosmic-ray events and to improve the angular resolution, hard cuts on the image amplitude ($\geq$ 400 photo-electrons) were applied to the data. Thereby, systematic errors were greatly reduced at the expense of a higher energy threshold of about 675 GeV for the whole data set. The background of charged cosmic rays was estimated from off-source runs, recorded between April and June 2004, with a total live time of 6.8 h, taken at zenith angles between 16° and 38° (mean: 22°), which is very similar to the zenith angle coverage of the actual data taken on RX J0852.0−4622.

Figure 3 shows the radial distribution of the excess of γ-rays as a function of the reconstructed squared angular distance, θ^2, from the nominal centre of the SNR. In the region $\theta^2 \leq 1$ deg^2 a clear excess of 330±30 events (1.7±0.2 min^{-1}) is seen. The significance of the signal was calculated to be 11 σ using Li and Ma [1983]. The excess distribution is much wider

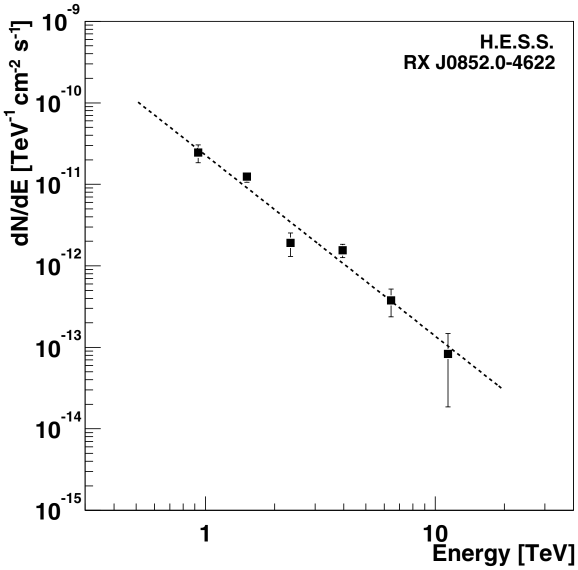


Figure 4: **Differential energy spectrum of RX J0852.0−4622.** The data are well described by a single power-law (dashed line).

than measured for point-like sources. Therefore, the source is clearly extended with a characteristic angular size of the order of 1°. The inset of Fig. 3 shows good agreement of on-source and off-source data in the range above 1 deg^2. The distributions are not flat outside the signal region since the acceptance drops off towards higher values of θ^2.

A sky map of the excess is displayed Fig. 1b). No correction for the camera acceptance was applied. The overlaid contour plot is the X-ray measurement from ASCA [Slane et al. 2001]. γ-ray and X-ray counts are found to be well correlated.

The differential energy spectrum is shown in Fig. 4 and is well described by a power-law. The spectrum appears to be hard with a photon index of 2.2. The integral flux above 1 TeV is comparable to the flux of the Crab nebula above this threshold.

6. Summary

Significant TeV γ-ray emission from RX J1713.7−3946 and RX J0852.0−4622 was observed with H.E.S.S. allowing spatial and spectral analyses. The 2003 detection of RX J1713.7−3946 with H.E.S.S. could be confirmed with high significance (about 30σ) in 2004 with the full telescope array. The TeV morphology appears to be very similar to that seen in X-rays. For RX J0852.0−4622 the significance of the signal is 11σ with an extension as seen in X-rays. Both spectra can be described by a power-law. The fit parameters are summarised in Table I. An alternative determination of the morphology for both sources in which no hard cuts has been used yields similar sky maps. The detection of strong emission extending to at least 10 TeV in two shell-type SNRs is direct evidence for the acceleration of charged particles to at least 100 TeV in these objects.

Table I **Spectral parameters of the SNRs.** Shown are the differential flux at 1 TeV (Φ_0), the photon index (Γ) and the integral flux above 1 TeV ($\Phi(E > 1\,\mathrm{TeV})$) as obtained from fits of a power-law $\Phi(E) = \frac{\mathrm{d}N}{\mathrm{d}E} = \Phi_0 \times \left(\frac{E}{1\,\mathrm{TeV}}\right)^{-\Gamma}$ to the data. Systematic uncertainties are estimated to be 30% on the flux and 10% on the photon index.

	RX J1713	RX J0852
Φ_0 [10^{-11} TeV^{-1} cm^{-2} s^{-1}]	1.7 ± 0.2	2.3 ± 0.4
Γ	2.19 ± 0.09	2.2 ± 0.2
$\Phi(E > 1\,\mathrm{TeV})$ [10^{-11} cm^{-2} s^{-1}]	1.46 ± 0.17	1.9 ± 0.4

Two scenarios are discussed to be the origin of the TeV γ-rays. Inverse Compton (IC) scattering of leptons on photons of the cosmic microwave background and other photon fields, and π^0 decay γ-rays from inelastic interactions of protons with the ambient gas. Detailed spatial and spectral studies with the H.E.S.S. detector, together with data from other wavelength bands, could allow to probe the acceleration processes in detail and should allow us to distinguish the relative contributions of leptons and protons to the observed emission.

More data on RX J0852.0−4622 will be taken with H.E.S.S. in the upcoming visibility period, detailed, spatially resolved studies of RX J1713.7−3946 will be published soon.

Acknowledgments

The support of the Namibian authorities and of the University of Namibia in facilitating the construction and operation of H.E.S.S. is gratefully acknowledged, as is the support by the German Ministry for Education and Research (BMBF), the Max Planck Society, the French Ministry for Research, the CNRS-IN2P3 and the Astroparticle Interdisciplinary Programme of the CNRS, the U.K. Particle Physics and Astronomy Research Council (PPARC), the IPNP of the Charles University, the South African Department of Science and Technology and National Research Foundation, and by the University of Namibia. We appreciate the excellent work of the technical support staff in Berlin, Durham, Hamburg, Heidelberg, Palaiseau, Paris, Saclay, and in Namibia in the construction and operation of the equipment. We thank Patrick Slane for kindly supplying the ASCA X-ray data shown in Fig. 1b).

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