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Observation of the shell-type supernova remnant RX J0852.0$-$4622 with H.E.S.S.

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Shell-type supernova remnants are prime candidates for the acceleration of galactic cosmic rays. The detection of TeV γ-ray emission from the shells is believed to be a key to unravelling the underlying acceleration mechanisms. In 2004 and 2005, the shell-type supernova remnant RX J0852.0$-$4622 (also called G266.2-1.2) was observed and detected with H.E.S.S., an array of four Imaging Atmospheric Cherenkov Telescopes located in Namibia, dedicated to observations of γ-rays above 100 GeV. The energy spectrum of the source can be described by a power law and the integral flux is similar to the flux from the Crab nebula. The emission region is found to be clearly extended, making RX J0852.0$-$4622 the second shell-type supernova remnant which has been spatially resolved in TeV energies [1]. The morphology of the TeV emission is well correlated with the X-ray morphology. The results of the observations will be presented and possible implications will be discussed.

1. Introduction

RX J0852.0$-$4622 is a young shell-type supernova remnant (SNR) in the line of sight to the Vela SNR. The observed X-ray emission of RX J0852.0$-$4622 extends over a roughly circular region with a diameter of $\approx 2^\circ$ with a brightening towards the north-western, western and southern part of the shell and towards the centre. The observed X-ray spectrum is clearly dominated by a continuum, which indicates a non-thermal origin of the emission [2, 3, 4, 5]. Radio observations show only weak emission from the shell and no emission from the centre [6, 7]. The age has been calculated to be $\approx 700\,\mathrm{y}$ [8, 9, 3, 10]. The distance is in the range of 200–400 pc [8, 9, 10]. A much larger distance of 1–2 kpc is suggested in [4].

Emission of γ-rays from the north-western part of RX J0852.0$-$4622 was detected by the CANGAROO collaboration [11]. Here we report on the detection of the entire SNR by H.E.S.S. [12].

H.E.S.S. (High Energy Stereoscopic System) is an array of four imaging Cherenkov telescopes dedicated to the detection of VHE (very high energy) γ-rays with energies above 100 GeV [13]. Each telescope has a tessellated mirror with an area of $107\,\mathrm{m}^2$ [14, 15] and a camera consisting of 960 photomultiplier tubes [16]. A central trigger unit requires the observation of an air shower by at least two telescopes [17]. 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 [13]. 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.

H.E.S.S. observed RX J0852.0$-$4622 in February 2004 for a total live time of 3.2 h and between December 2004 and April 2005 for a much longer exposure time of 28 h. Cuts on scaled image parameters which were optimised on Monte Carlo simulations were applied to reduce the cosmic-ray background [18]. The shower

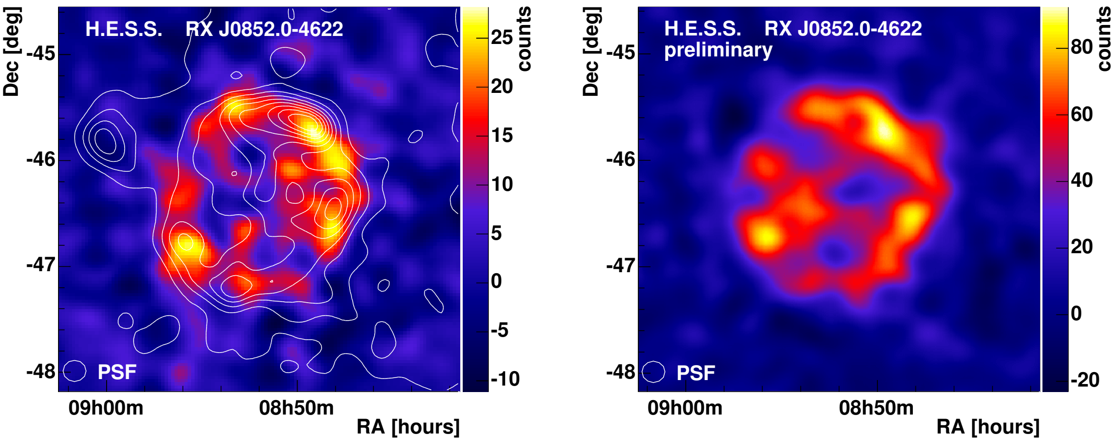

Figure 1. Count map of γ-rays from the direction of RX J0852.0−4622 after background subtraction. The data are smoothed with a Gaussian ($\sigma = 0.1^\circ$) representing the angular resolution of the instrument. The point spread function (PSF) is indicated by a circle. γ-ray features smaller than the PSF should not be considered as real. The left panel shows the data from the February 2004 observation period. The lines denote equidistant contours of smoothed ($\sigma = 0.1^\circ$) X-ray data from the ROSAT All Sky Survey, with energies restricted to above 1.3 keV. The right panel shows a sky map of the H.E.S.S. data of the 2004/2005 reobservations which reproduces the previously published data. The axes show J2000.0 equatorial coordinates.

directions were reconstructed from shower images in different cameras. The photon energy was estimated with a typical resolution of 15% from the image intensity and shower geometry.

2. H.E.S.S. Observations

Figure 1 shows a smoothed sky map of the excess of γ-rays from the direction of RX J0852.0−4622. No correction for the instrument's acceptance, which drops by $\approx 20\%$ towards the source boundary at 1° distance from the centre of the remnant, was applied. A clear excess of γ-rays from an extended, circular region with a radius of $\approx\ 1^\circ$ is visible. The brightest emission region is the north-western part of the shell, coincident with the excess detected by CANGAROO. In the left panel of Fig. 1 the February 2004 data is shown which was published previously [12]. Within a circular region with a radius of 1° around the nominal centre of RX J0852.0−4622 (RA 8h52$\overset{\mathrm{m}}{.}$0, Dec $-46^\circ 22'$), an excess of (700 ± 60) events corresponding to a photon rate of $(3.7 \pm 0.3)\,\mathrm{min}^{-1}$ was found. The significance of the signal, calculated using a likelihood approach [19, equation (17)], is $12\,\sigma$.

The overlaid contour plot represents the X-ray measurement by the ROSAT All-Sky Survey [20]. The X-ray energy was restricted to above 1.3 keV, corresponding to the initial discovery [2]. We note that the X-ray data are contaminated by emission from the Vela SNR and RCW 37 (east of RX J0852.0−4622). Ignoring this, and the fact that the γ-ray data were not corrected for acceptance and exposure, the correlation coefficient between the γ-ray counts and X-ray counts in bins of $0.3^\circ \times 0.3^\circ$ size was found to be 0.67 ± 0.05.

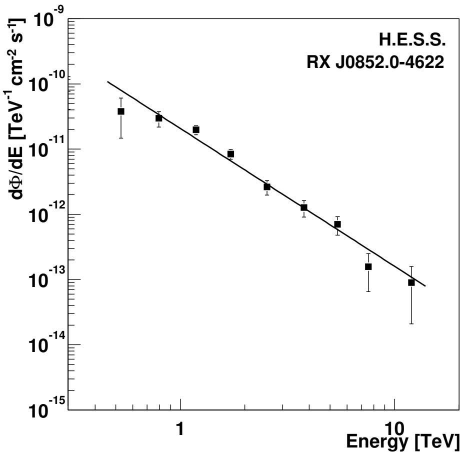

Figure 2. Differential photon flux spectrum of the γ-rays of the February 2004 data set. The solid line is the result of a power law fit. The error bars denote $\pm 1\sigma$ statistical errors.

The right panel of Fig. 1 shows the excess of γ-rays obtained in a part of the follow-up observations with H.E.S.S. in 2004 and 2005 with a live time of 12 h. It reproduces well the result obtained previously, with a much improved statistics. The analysis of this data set is still ongoing.

The differential photon flux spectrum of the γ-ray emission from the entire SNR obtained with the February 2004 data set is shown in Fig. 2. The spectrum is well described by a power law

$$\varphi(E) = \frac{\mathrm{d}\Phi}{\mathrm{d}E} = (2.1 \pm 0.2) \times 10^{-11}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{TeV}^{-1} \cdot \left(\frac{E}{1\,\mathrm{TeV}}\right)^{-(2.1\pm0.1)}$$

which is shown as a solid line in Fig. 2. The corresponding integral flux above 1 TeV is $\Phi(E > 1\,\mathrm{TeV}) = (1.9 \pm 0.3_{\mathrm{stat}}) \times 10^{-11}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ which similar to the integrated flux from the Crab nebula above this energy [21].

The systematic errors were estimated to be 0.2 for the photon index and 30% for both the differential flux at 1 TeV and the integral flux.

3. Discussion

There are two basic mechanisms for TeV γ-ray production in young SNRs – inverse Compton scattering (IC) of multi-TeV electrons on photons of the cosmic microwave background (CMB) and other target photon fields, and π^0-decay γ-rays from inelastic interactions of accelerated protons with ambient gas.

The measured γ-ray flux spectrum of RX J0852.0−4622 translates into an energy flux of $w_\gamma(1 - 10\,\mathrm{TeV}) = \int_{1\,\mathrm{TeV}}^{10\,\mathrm{TeV}} E\varphi(E)\mathrm{d}E \approx 7 \times 10^{-11}\mathrm{erg\,cm}^{-2}\mathrm{s}^{-1}$, which is quite close to the X-ray energy flux of the entire remnant of $w_{\mathrm{X}}(0.5 - 10\,\mathrm{keV}) \approx 10^{-10}\mathrm{erg\,cm}^{-2}\mathrm{s}^{-1}$ [4]. If the γ-ray emission is entirely due to the IC process on CMB photons, the magnetic field in the γ-ray production region cannot significantly exceed the interstellar value of several μG [22]. If one assumes a larger magnetic field in the remnant the IC scenario would therefore become less favourable. On the other hand, the TeV flux can be easily explained in terms of interactions of accelerated protons with the ambient gas. The total energy in accelerated protons in the range $10 - 100\,\mathrm{TeV}$ required to provide the observed TeV flux can be estimated from the characteristic cooling time of protons through the π^0 production channel $t_{pp\to\pi^0} \approx 4.5 \times 10^{15}(n/1\,\mathrm{cm}^{-3})^{-1}\mathrm{s}$ and the γ-ray luminosity $L_\gamma(1-10\,\mathrm{TeV}) = 4\pi d^2 w_\gamma(1-10\,\mathrm{TeV}) \approx 3\times 10^{32}(d/200\,\mathrm{pc})^2\,\mathrm{erg/s}$ to be $W(10-100\,\mathrm{TeV}) \approx t_{pp\to\pi^0} \times L_\gamma(1-10\,\mathrm{TeV}) \approx 1.5\times 10^{48}(d/200\,\mathrm{pc})^2(n/1\,\mathrm{cm}^{-3})^{-1}\,\mathrm{erg}$. Assuming that the power-law proton spectrum with the same spectral slope to the photon spectrum continues down to $E \approx 1\,\mathrm{GeV}$, the total energy in protons is estimated to be $W_{\mathrm{tot}} \approx 10^{49}(d/200\,\mathrm{pc})^2(n/1\,\mathrm{cm}^{-3})^{-1}\mathrm{erg}$. Thus, for distances to the SNR in the order of $d \approx 200\,\mathrm{pc}$ the conversion of several percent of the assumed mechanical explosion energy of 10^{51} erg to the acceleration of protons up to $\geq 100\,\mathrm{TeV}$ would be sufficient to explain the observed TeV γ-ray flux by nucleonic interactions in a medium of density comparable to the average density of the interstellar medium, $n \approx 1\,\mathrm{cm}^{-3}$. For larger distances a correspondingly higher fraction of the explosion energy would have to be converted into the acceleration of protons.

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