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# OBSERVATIONS OF SHELL-TYPE SUPERNOVA REMNANTS WITH H.E.S.S.

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**Abstract.** It is widely believed that the shells of supernova remnants (SNRs) are the sources of the Galactic Cosmic Rays up to energies of about $10^{15}$ eV. These high-energy hadrons interact with ambient material, and the subsequent neutral pion decay produces gamma rays in the GeV and TeV energy range.

H.E.S.S., a system of ground-based imaging Cherenkov telescopes dedicated to the observation of gamma rays with energies of several hundred GeV up to tens of TeV, is an ideal instrument for the observations of high-energy gamma-ray emission from SNRs. In the recent years H.E.S.S. observed a number of SNRs. Firm detections have been reported from the well-known SNRs RX J1731-3946 and RX J0852-4622 as well as the interaction of W28 with molecular clouds. Further on, the Galactic scan conducted with H.E.S.S. revealed several other SNRs.

In this talk I will discuss some of the SNRs observed so far and discuss the implications with respect to Cosmic Ray acceleration.

## 1 Introduction

Shell-type supernova remnants (SNRs) are believed to be the sources of Galactic Cosmic Rays with energies up to $10^{15}$ eV. Supernova explosions can deliver the entire energy density observed in Cosmic Rays (); and particle acceleration is predicted to occur in the shock front of the supernova remnant (see e.g. ). Non-thermal X-ray emission from supernova remnants, which is interpreted as being synchrotron radiation, proves the acceleration of electrons. The acceleration of hadrons, however, is still debated. Relativistic protons produce in interactions with ambient material $\pi^0$ mesons; the disintegration of these mesons subsequently produces gamma rays in the GeV and TeV energy regime. Gamma-ray astronomy is therefore an ideal tool to study hadron acceleration in supernova remnants.

The High Energy Stereoscopic System (H.E.S.S.) is an imaging Cherenkov telescope array dedicated to the observations of very high energy (VHE) gamma rays with energies of more than 100 GeV, up to several tens of TeV. Located in Namibia on the southern hemisphere it, is in an ideal place to observe the central part of the Galactic plane. In the first years of observations a number of shell-type supernova remnants have been detected, a not complete list is discussed in this paper.

## 2 H.E.S.S. observations of SNRs

### 2.1 RX J1713−3964

The supernova remnant RX J1713−3964 (also called G 347.3-0.5) was one of the first sources observed with H.E.S.S. and the first confirmed extended VHE gamma-ray source (; ; ). An image of the gamma-ray excess is shown in the left panel of Fig. 1. The gamma-ray morphology follows that seen in X-rays, indicating that X-rays and gamma rays originate in the same region. The detection of gamma-rays with energies up to 100 TeV proves particle acceleration up to $10^{15}$ eV. Whether these particles are electrons or protons cannot be concluded from gamma-ray observations alone. Further assumptions have to be made as gamma-ray emission can be both, inverse Compton radiation of electrons and $\pi^0$-decay emission from protons.

The recent detection of an energy cut-off in the X-ray spectrum and the modelling of the entire electromagnetic emission of the supernova remnant () showed that the observed emission can be explained as being of

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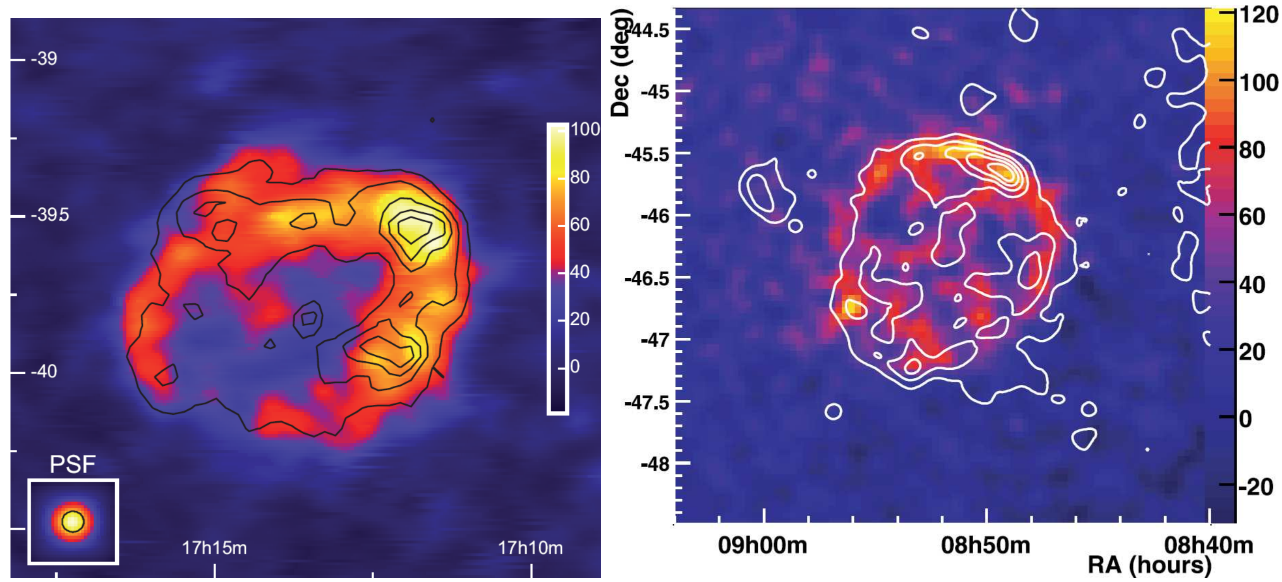


**Fig. 1.** H.E.S.S. gamma-ray images (colour scale) for shell-type supernova remnants with overlaid X-ray emission contours. *Left panel:* RX J1713−3964 with ASCA X-ray data (). *Right panel:* RX J0852−4622 with ROSAT X-ray contours ().

hadronic origin under assumption of a high magnetic field around 200 $\mu$G. However, a solely electronic model would be possible as well, assuming a magnetic field of 14 $\mu$G and the requirement of two distinct electron components.

### 2.2 RX J0852−4622

The second extended TeV source discovered by H.E.S.S. is the supernova remnant RX J0852−4622 (also called G 266.2−1.2 or Vela Junior). As shown in the right panel of Fig. 1 the gamma-ray morphology is a clear shell with a diameter of 2° which follows the X-ray morphology (). Detailed modelling of the emission over all wavelength () showed that the emission is consistent with a hadronic scenario in the case of a high magnetic field of about 120 $\mu$G. Such a high field is further supported by the observation of very thin X-ray filaments (). A pure electronic scenario would require quite a low magnetic field of about 6 $\mu$G, contradicting the expected magnetic field amplification in supernova remnant shells ().

### 2.3 RCW 86

A third object in the class of shell-type SNRs with gamma-ray emission, non-thermal X-ray emission and only faint radio emission is RCW 86 (also known as G315.4−2.3 or MSH 14−63) (). The gamma-ray emission shows an almost complete shell (left panel of Fig. 2). The X-ray morphology (right panel of Fig. 2), however, is a rather bipolar structure with the brightest part of the emission in the south-west; and therefore the case of RCW 86 is somewhat different to the objects discussed before. Comparison of X-ray and gamma-ray emission in a leptonic scenario leads to a magnetic field of about 20 $\mu$G. Given the large uncertainties in age and distance to the remnant, a hadronic scenario would be possible as well.

### 2.4 W 28

The case of W 28 (also called G 6.4−0.1) is completely different to the sources discussed above. The shell of W 28 was seen only in radio. X-ray observations show only thermal emission from the interior of the SNR. This remnant is rather old, 35 − 150 kyr, and it is expected that the highest energy electrons (those that produce non-thermal X-ray emission) have already lost their energy, so that no synchrotron emission is seen anymore in X-rays. The left panel of Fig. 3 shows the gamma-ray excess map obtained with H.E.S.S. (). Gamma-ray

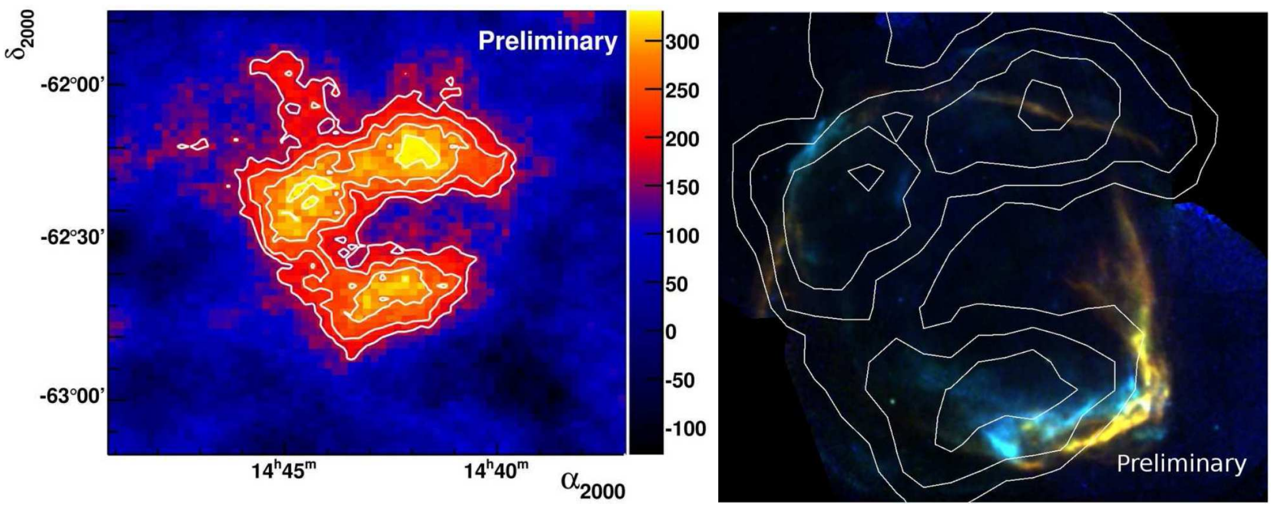


**Fig. 2.** Shell-type supernova remnant RCW 86 (). *Left panel:* H.E.S.S. gamma-ray excess image (colour scale) with overlaid 3, 4, 5, 6 $\sigma$ significance contours. *Right panel:* XMM X-ray image (colour scale) with H.E.S.S. significance contours.

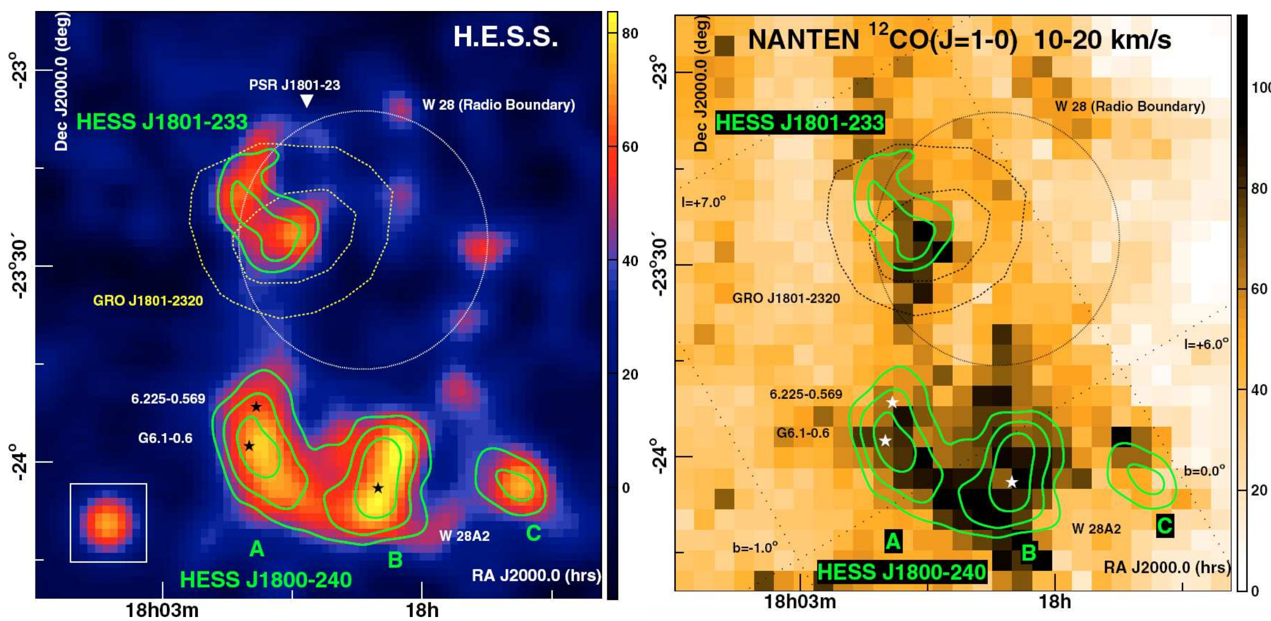


**Fig. 3.** Supernova remnant W 28 (). *Left panel:* H.E.S.S. gamma-ray excess map with overlaid 4, 5 and 6 $\sigma$ significance contours. The extension of the radio shell is indicated by a white dashed circle. *Right panel:* CO emission (colour scale) indicating molecular clouds with overlaid H.E.S.S. significance contours.

emission is detected from the direction of W 28, but it is not directly connected to the SNR. It is, however, correlated with molecular clouds seen in radio, as shown in the right panel of Fig. 3. Molecular clouds are regions of high matter density, therefore providing additional target material for the proton-proton interactions. Even though other possible counterparts for the gamma-ray emission exist, the correlation with regions of high density in the vicinity of the SNR makes it likely that protons were accelerated in the supernova shell.

## 3 Discussion

Shell-type supernova remnants are established as gamma-ray emitters. The morphology of young remnants generally show a good agreement between gamma-ray and X-ray morphologies. The emission of non-thermal X-rays interpreted as synchrotron emission of relativistic electrons is a proof for particle acceleration in the remnant's shells. Under certain assumptions on the parent electron distribution and for low to moderate magnetic fields the observed gamma-ray emission can be interpreted as being inverse Compton scattering of electrons off ambient photon fields. On the other hand, the gamma-ray emission can be easily powered by proton interactions assuming the transfer of about 10% of the supernova's explosion energy to protons. This scenario requires a higher magnetic field in order to suppress inverse Compton emission. Magnetic fields are expected to be amplified in the SNR's shock (); therefore the acceleration of protons in SNR shells seems to be likely. The disentanglement of leptonic and hadronic emission remains an open question.

In old SNRs no inverse Compton emission is expected and any gamma-ray radiation can be attributed to proton interactions assuming sufficient target material is provided. The detection of gamma-ray emission from the direction of W 28 coincident with molecular clouds is a striking example for possible hadronic emission. Other possible counterparts for this emission, and the problem of connecting the SNR with the clouds and gamma-ray emission in general, are and will remain the major problems in this kind of observations.

## 4 Conclusion

Gamma-ray observations show that shell-type SNRs are indeed possible accelerators of protons and thus possible sources of the Cosmic Rays. The remaining problem of discriminating inverse Compton and hadronic emission can be overcome by the observation of further features in the gamma-ray spectrum. *Fermi*/LAT (recently launched) and H.E.S.S. II (under construction) will extend the observable gamma-ray spectrum to lower energies. Future observatories like CTA will allow the study of the high-energy end of the spectrum.

The final proof of hadron acceleration in SNRs would be the detection of neutrinos from the supernova remnant shells. With the work discussed above, gamma-ray observations can identify the most promising targets for the search of neutrino emission.

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