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H.E.S.S. Observations of Shell Type SNR.

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Over the past few years, H.E.S.S. has observed a number of shell-type supernova remnants (SNRs) in order to determine if they are capable of multi-TeV particle acceleration. Apart from RX J1713.7−3946 and RX J0852.0−4622 (Vela Junior) discussed separately at this conference, other candidates such as W28, SN 1987A, IC-443, Monoceros Loop/Rosette Nebula and SN 1006 are among several highly-ranked targets, based on previous TeV results and/or multi-wavelength information. We briefly outline the motivation for these H.E.S.S. observations and summarise details of several candidates.

1. Introduction

Shell-type SNRs have long-been considered the dominant accelerators of Galactic Cosmic-Rays (CRs) based on theoretical grounds (diffusive shock acceleration theory) and the observed properties of the CRs at Earth (spectra and composition). A key implication of this is that shell-type SNRs would be sources of TeV γ radiation at levels generally detectable by ground-based instruments such as H.E.S.S. Under this scenario, TeV γ-rays would be produced from the interaction of accelerated CRs with dense, local matter. The discovery by H.E.S.S. of shell-like TeV γ-ray emission from RX J1713.7−3946 and RX J0852.0−4622 indeed confirms that such SNRs are capable of multi-TeV particle acceleration at their shock-fronts. A key question is whether or not shell-type SNRs as a class are responsible for Galactic CR. If so, is this limited to specific sub-classes of shell-type SNR? For example, both RX J1713.7−3946 and RX J0852.0−4622 are relatively young SNR expanding into dense environments. They are still likely to be in the Sedov expansion phase, generally believed to be optimal for CR acceleration. Questions remain as to whether other classes of shell-type SNR are able to accelerate CR. For example, older SNR which have entered the radiative phase (in which case the CR have mostly escaped), composite SNR which may have an additional, central source of energy (possibly a pulsar-powered nebula), and SNR that have expanded into less-dense surroundings, could also be multi-TeV particle accelerators. Clearly, observations of a variety of shell-type SNR are needed to answer these questions. H.E.S.S. has so far (as of June 2005) observed a total of eight shell-type SNR in dedicated observations over the past 3 years in an on-going programme. Additional candidates will also be observed in 2005.

Briefly, H.E.S.S. (High Energy Stereoscopic System) is an array of four Imaging Atmospheric Cherenkov Telescopes situated in the Southern Hemisphere (Namibia 1800 m a.s.l.), and designed to detect γ-rays covering the energy range $\sim$ 100 GeV to above 10 TeV. Utilising the stereoscopic technique, H.E.S.S. achieves a sensitivity roughly a factor 10 better than previous instruments covering the TeV band. Further technical details concerning H.E.S.S. can be found in [13]. The angular resolution of H.E.S.S. (few arcmin) and its acceptance field of view (FWHM $\sim$3.5°) is ideal for the study of shell-type SNR which are generally extended in size. The H.E.S.S. results on RX J1713.7−3946 [1] and RX J0852.0−4622 [5] clearly show that detailed morphological studies are possible. In the next section we summarise several SNR candidates that have been observed by H.E.S.S. Where quoted, the H.E.S.S. exposure time is dead-time-corrected, and data have been screened according to various quality selection criteria (see [3] for details).

2. The Shell-Type SNR Sample & H.E.S.S. Observations

W28 (G6.4−0.1): W28 is an old-age (∼35000 to 150000 yr) composite SNR exhibiting shell-like radio and centre-filled X-ray morphologies [12, 22]. Distance estimates are placed between 1.8 and 3.3 kpc. A distinguishing aspect of W28 is that its eastern boundary appears to be interacting with a very dense molecular cloud [10, 6] (density $n \geq 10^3$ cm^{-3}). This is borne out by the very high concentration of radio OH masers in this region. W28 is therefore a prime candidate for hadronic TeV γ-ray emission and the fact that the X-ray emission appears to be largely thermal in nature. A host of other interesting sources are nearby, in particular the HII regions M8 (Lagoon Nebula) and W28A-2 [12], the pulsar PSR J1801−23, and the EGRET source 3EG J1800−2338. Exposure of the W28 region by H.E.S.S. has been accumulated over the years 2004 and 2005. The 2004 dataset amounts to 20.6 h (livetime) and includes a part of the Galactic Plane scan data (where the tracking distance to W28 is less optimal). The 2005 dataset amounts to 7.6 hours, giving a total of 28.2 h.

SN 1987A: SN 1987A was the nearest and brightest SN seen in the 300 years. Discovered Feb 23 1987, its long-term radio and X-ray output has been steadily increasing [18, 16, 7]). H.E.S.S. data were taken during the southern summers of 2003/2004 and 2004/2005 (∼6400 and 6900 days respectively after the SN). Although the *Chandra* X-ray spectrum is well explained by a thermal model, spatial correlation with radio, and an indication from XMM data for a power-law component extending up to 10 keV could suggest the presence of non-thermal X-ray emission. A total of 5.6 h H.E.S.S. data have been taken on SN 1987A. The H.E.S.S. field of view encompasses a number of other interesting objects including 30 Dor C (possibly a superbubble), the Crab-like plerion PSR B0540-69, the SNR (plerionic) N157B, and the X-Ray binary LMC X-1.

IC 443 (G189.1+3.0): IC 443 is a composite SNR with an embedded X-ray plerion [17, 9] and possible EGRET source association (3EG J0617+2238). Distance estimates for IC 443 are in the range 1 to 1.5 kpc and age 1600 to 3000 years. IC 443 is also likely interacting with an adjacent molecular cloud, itself associated with the HII region S249 to the north [21]. Evidence for TeV emission from IC 443 comes from observations with the HEGRA IACT-System [20]. So far only a few hours exposure (2.5 h) has been obtained on IC 443.

Monoceros Loop (G205.5+0.5)/Rosette Nebula: Monoceros Loop [11] is a very large (diameter $\sim 3.5°$) and old-age (∼30000 to 150000 yr) SNR which appears to be interacting with a dense molecular cloud in the SW region. This SW region contains the famous Rosette Nebula (HII emission nebula) which itself is likely powered by the young open cluster NGC 2244. CO observations show that the densest regions are concentrated along the boundary between Monoceros Loop and the Rosette Nebula [24]. Associated X-ray emission is diffuse and apparently thermal in nature. The hard spectrum X-ray source SAX J0635.2+0533 is coincident with the pulsar PSR J0635+0533 [14]. Previous TeV observations of the Monoceros Loop region were carried out with the HEGRA IACT-System (obtaining over 100 hrs) yielding upper limits from various regions [2]. The H.E.S.S. exposure from 2004/2005 amounts to 5.1 h which is somewhat similar to the sensitivity achieved by the HEGRA dataset.

SN 1006: SN 1006 exhibits shell-like morphology (dominated by NE and SW rim emission) in both radio and X-ray energies, and was the first shell-type SNR shown to exhibit non-thermal X-ray emission [15]. CANGAROO results suggesting the presence of TeV γ-ray emission from the NE rim [23] were subsequently not confirmed by recent (more sensitive) H.E.S.S. observations [4]. A reanalysis of the H.E.S.S. SN 1006 dataset employing methods with improved sensitivity at energies $E > 1$ TeV is now underway.

RCW 86 (G315.4−2.3): RCW 86 (distance ∼2.5 kpc, age ∼3000 yrs) is somewhat similar to RXJ1713.7−3946 in that it emits non-thermal X-rays and appears to be interacting with an adjacent molecular cloud [8, 19]. Hints for TeV emission come from CANGAROO observations [25]. Dedicated H.E.S.S. observations of this SNR have been taken in 2004 and 2005 for a total of ∼10 hours. Some extra exposure (few hours in 2005) will soon also be available from scan of the Galactic Plane region (l=300° to 330°).

3. Summary

A increasing number of Shell-Type SNR are being observed by H.E.S.S. in an attempt to establish this class of source as multi-TeV particle accelerators. Apart from the two very strong TeV emitters RX J1713.7−3946 and RX J0852.0−4622 (with total TeV fluxes at the ∼1 Crab level) that show clear evidence for shell-like morphology in TeV γ-rays, a number of other potential candidates (representing various SNR sub-classes) are now under serious study. For all of the sources described here, data analysis is presently ongoing and updated results for selected candidates will be presented at the conference.

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