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Upper Limits on Gamma-ray Emission from Supernovae Serendipitously Observed with H.E.S.S.

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Abstract. It is hypothesized that some young supernovae might have the correct properties to accelerate cosmic rays, which in turn might generate gamma-ray emission by-products. We search for gamma-ray excesses towards supernovae in nearby galaxies which were serendipitously within the field of view of the HESS telescopes within a year of the supernova event. HESS cherenkov air-shower data collected between December 2003 and March 2015 were considered and compared to recent catalogs. Nine candidate supernovae were identified and analysed. No significant emission from these supernovae has been found, and upper limits for their very high energy emission are reported.

Keywords. gamma rays: observations, supernovae: general, cosmic rays

1. Introduction

It is well established that supernova remnants (SNRs) can be emitters of high-energy and very-high-energy (E>100 GeV) gamma-rays and that cosmic-ray (CR) protons and nuclei accelerated locally are responsible for this gamma-ray emission in some of these objects (e.g. Ackermann *et al.* 2013, Aharonian *et al.* 2008), while other objects remain probable CR accelerators (e.g. Abdalla *et al.* 2016, Lau *et al.* 2017). Nevertheless, the SNRs under strong scrutiny from a very-high-energy gamma-ray perspective are often 10^2-10^4 years old and have never been conclusively shown to be PeV (10^{15} eV) CR acceleration sources, despite some shell-type SNRs still being potential candidates (e.g. Fukui *et al.* 2012, Gabici *et al.* 2014).

It has been theorized that young supernovae (SNe) might have the correct properties to accelerate CRs to PeV energies within a few months to a few years after the progenitor explosion (e.g. Cardillo *et al.* 2015, Katz *et al.* 2011, Murase *et al.* 2011, Marcowith *et al.* 2014).

This can occur only in a very dense circumstellar medium (CSM) as this results in sufficient number of particles entering the shock, as well as creation and growth of plasma instabilities. This last process is driven by the particle acceleration itself, leading to a fast magnetic field amplification. The amplified, turbulent magnetic fields allow CR particles to be accelerated to PeV energies or beyond. Accelerated hadrons will interact with the dense surrounding matter and produce very high energy gamma rays and neutrinos via pion production/decay. Dense CSM is expected around core collapse SNe with high

Table 1. The list of SN positions tested for H.E.S.S. gamma-ray excess emission. The list was compiled using a system of cuts described in Section 2.2. The name, host galaxy, coordinates, estimated distance, SN type and discovery date is shown for each SN.

SN Name	**Host galaxy**	**RA [J2000]**	**DEC [J2000]**	**Dist. [Mpc]**	**Type**	**Disc. date**
SN 2004cx	NGC 7755	23h47m52.86s	$-30^\circ31'32.6''$	26 ± 5	II	2004-06-26
SN 2005dn	NGC 6861	20h11m11.73s	$-48^\circ16'35.5''$	38.4 ± 2.7	?	2005-08-27
SN 2008bk	NGC 7793	23h57m50.42s	$-32^\circ33'21.5''$	4.0 ± 0.4	IIP	2008-03-25
SN 2008bp	NGC 3095	10h00m01.57s	$-31^\circ33'21.8''$	29 ± 6	IIP	2008-04-02
SN 2008ho	NGC 922	02h25m04.00s	$-24^\circ48'02.4''$	41.5 ± 2.9	IIP	2008-11-26
SN 2009hf	NGC 175	00h37m21.79s	$-19^\circ56'42.2''$	53.9 ± 3.8	IIP	2009-07-09
SN 2009js	NGC 918	02h25m48.28s	$+18^\circ29'25.8''$	16 ± 3	IIP?	2009-10-11
SN 2011ja	NGC 4945	13h05m11.12s	$-49^\circ31'27.0''$	5.28 ± 0.38	IIP	2011-12-18
SN 2012cc	NGC 4419	12h26m56.81s	$+15^\circ02'45.5''$	$\sim 20 \pm$	II	2012-04-29

mass-loss rates and slow wind speeds; this applies particular to SN type IIp, IIb and IIn (Chevalier *et al.* 2016).

This possibility of CR acceleration in young SNe motivates a search for signatures of particle acceleration beyond TeV energies in H.E.S.S. Cherenkov air-shower data.

2. Analysis

2.1. *H.E.S.S. observations*

H.E.S.S., the High Energy Stereoscopic System, is an array of five imaging atmospheric Cherenkov telescopes (IACTs) located in the Khomas Highland of Namibia at an altitude of 1800 m above sea level. Four 12 m-diameter telescopes were operating from December 2003 and a 5th telescope of 28 m-diameter became operational in September 2012. In our analysis, the data of 3-4 of the 12 m telescopes has been utilised. This generally results in field of view and beam full-width half-maximum of 5° and $\sim$0.1°, respectively, and an energy threshold and energy resolution of $\sim$ 100 GeV and $\sim$ 15%, respectively (Aharonian *et al.* 2006). The SNe in our sample all occur within $\sim$3° of the centre of the field of view.

2.2. *Candidate Selection*

The online IAU Central Bureau of Astronomical Telegrams (CBAT) supernova catalogue † was downloaded to compile an initial, extensive list of SN candidates. The NASA/IPAC Extragalactic Database (NED) ‡ was then queried for the redshift of each SN host galaxy to compile a short-list of SNe with redshift z <0.01 to ensure that only SNe near enough to plausibly be observable at gamma-ray energies were considered. If a host galaxy was not stated for a given SN in the CBAT SN catalogue, the SN was discarded from the short-list. The H.E.S.S. database was then queried for air shower measurements in the direction of each short-listed SN, within a time-range beginning 7 days before the SN discovery date to a year after the SN discovery date. The SNe with coincidental H.E.S.S. data are presented in Table 1. All H.E.S.S. data taken from December 2003 until the 31st of December 2014 was searched, and all SNe presented on CBAT on the 30th of March, 2015 were considered. We removed type Ia and Ic SNe from our sample, because these types are unlikely to occur in an interstellar density large enough to accelerate CRs up to TeV energies.

† www.cbat.eps.harvard.edu/lists/Supernovae.html
‡ ned.ipac.caltech.edu/forms/z.html

Table 2. Observed statistics for each SNe (see text) and preliminary upper limits on the integrated flux above the energy threshold E_{Th}, and 1 TeV. These upper limits are derived with 95% confidence level assuming a power law spectrum of index 2

SNe	N_{on}	N_{off}	α	N_{excess}	Sig	Exp hrs	Delay day	E_{Th} (TeV)	$F(> E_{Th})$ $(10^{-13}$ cm^{-2}s$^{-1})$	$F(> 1\,\mathrm{TeV})$
SN 2004cx	169	10387	65	8.7	0.7	39.9	-6	0.18	10	1.9
SN 2005dn	571	11452	19	-38.6	1.5	53.1	-3	0.21	2.2	0.41
SN 2008bk	50	3652	54	-18.0	-2.3	9.6	98	0.21	6.0	4.8
SN 2008bp	32	1860	60.	1..1	0.2	4.7	272	0.21	29	5.5
SN 2008ho	9	369	33	-2.3	-0.7	1.4	36	0.33	16	7.7
SN 2009hf	43	1404	35	3.3	0.5	4.0	0	0.21	20	5.3
SN 2009js	14	711	67	3.4	1	4.8	94	0.63	15	11
SN 2011ja	56	834	15	-1.2	-0.2	3.8	91	0.23	13	3.9
SN 2012cc	7	660	74	-1.9	-0.7	3.0	53	0.72	15	10

Notes: Exp gives the lifetime of the observations, Delay the number of days beetween first observation and SN discovery and Sig, the significance.

2.3. *Data Analysis*

Standard quality cuts were applied to remove bad-quality data from each data set, and the Model analysis outlined in (de Naurois *et al.* 2009) was employed for each candidate SN. For a given SN, multiple OFF regions were selected via the reflected-region method (Berge *et al.* 2007) to estimate a background of gamma-ray-like events which to subtract from the gamma-ray-like events detected in the ON-region (0.6 deg radius), selected on the SN position as for a point source. Results were confirmed using the H.E.S.S. Analysis software version hap_ICRC2015, with the ImPACT analysis framework (Parsons *et al.* 2014) and standard cuts.

For each 28-minute observation run which passed the criteria outlined in Section 2.2, the excess was computed (using $N_{excess}=N_{on} - \alpha N_{off}$) as well as the cumulative statistical significance using Equation 17 of Li & Ma 1983. Given the serendipitous nature of the observations presented in this report, the live time varies between ∼1 and ∼50 hours (see Table 2).

2.4. *Results*

Table 1 lists the observed supernovae along with corresponding host galaxies, coordinates, distance, type and discovery date. Distances range between 4 and 54 Mpc and discovery dates range between 2004 and 2012.

In Table 2 we report the relevant statistics of the gamma-ray observations and the TeV gamma-ray upper limits set by H.E.S.S.. No significant TeV emission is found towards any of the SNe within one year of the initial explosion.

Plots of >1 TeV gamma-ray emission vs time binned on a nightly basis are presented in Fig. 1. All SNe are consistent with having zero TeV emission within the sensitivity limits of our observations.

3. Conclusion

We search for TeV gamma-ray emission from supernovae serendipidously observed with the H.E.S.S. gamma-ray telescope, amending previous efforts (Lennarz *et al.* 2013). We find no significant detection above >1 TeV, a result that can be linked to other recent non detections (Ackermann *et al.* 2015, Ahnen *et al.* 2017). Another related result is the non

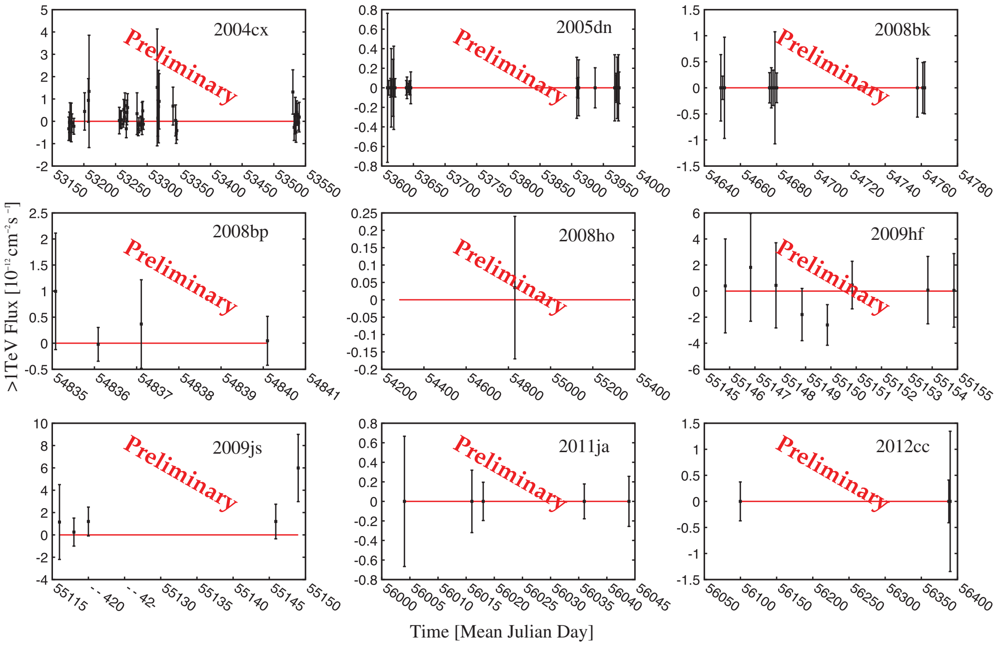

Figure 1. Light curves of the 9 observed SNe.

detection of nearby SN1987A (Aharonian *et al.* 2015), despite predictions (Völk *et al.* 2011).

These limits on gamma-ray emission can translate into limits on the physical environment of these SN events - something to be investigated in future papers.

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