Preliminary results from a search for TeV γ-ray emission from SN1987A and the surrounding field with H.E.S.S

G. Rowell*, J. Hinton*, W.Benbow* and H.E.S.S. Collaboration†

*Max Plank Institut für Kernphysik, Heidelberg, Germany
†http://www.mpi-hd.mpg.de/hfm/hess

Abstract. H.E.S.S. has observed the very young supernova remnant SN1987A during 2003 in a search for TeV γ-ray emission. These observations were taken during a build-up phase of H.E.S.S. with 2 operating telescopes, $\sim$6400 days after the initial explosion. Preliminary analysis so far reveals no convincing evidence for TeV emission and the 99% upper limit is compared with a predicted light curve. The H.E.S.S. field of view encompasses a number of other interesting objects including the X-ray shell 30 Dor C, the Crab-like plerion PSR B0540-69, the SNR N157B, and the X-ray binary LMC X-1. These objects may be associated with several features seen in the H.E.S.S. skymaps at marginal significances, and further observations in 2004/2005 with 4 telescopes will be valuable for confirmation.

INTRODUCTION

SN1987A is well known as the nearest and brightest SN seen for over 300 years. Discovered Feb 23 1987, its long-term radio and X-ray output has been steadily increasing (see [14, 15, 13, 8]). The X-ray light curve up to about 4000 days after the explosion has followed a t^2 relation. After that a further excess above this relation is seen up to about 5500 days after the SN explosion (H.E.S.S. data were taken 6400 days after the SN). XMM results are also summarised by Aschenbach [1]. 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. This increase in emission is explained in general terms by a contact of the SN shock with a ring of circumstellar matter thrown off from the SN progenitor. This contact is expected to lead to increased TeV γ-ray emission during the years 2002 and 2006 (eg. [10, 4]), and has motivated a search for TeV γ-rays by H.E.S.S. during its build-up phase in late 2003. SN1987A therefore provides a unique laboratory for the study of SNR evolution.

The H.E.S.S field of view (FWHM$\sim 3.5^\circ$) encompasses also a number of interesting regions including a SNR, plerions and the X-ray binary LMC X-1. A shell feature near the star 30 Dor C within 5 arcmin of SN1987A shows indication for non-thermal hard X-ray emission [19, 2] (see Fig.1). See also [5] for a discussion of XMM results for this region. The energetics of the shell estimated at 7×10^{51} erg is quite high for a single SNR, and may therefore result from more than one SN event. There are also two well-positioned candidates for plerionic emission, SNR B0540$-$693 containing the young

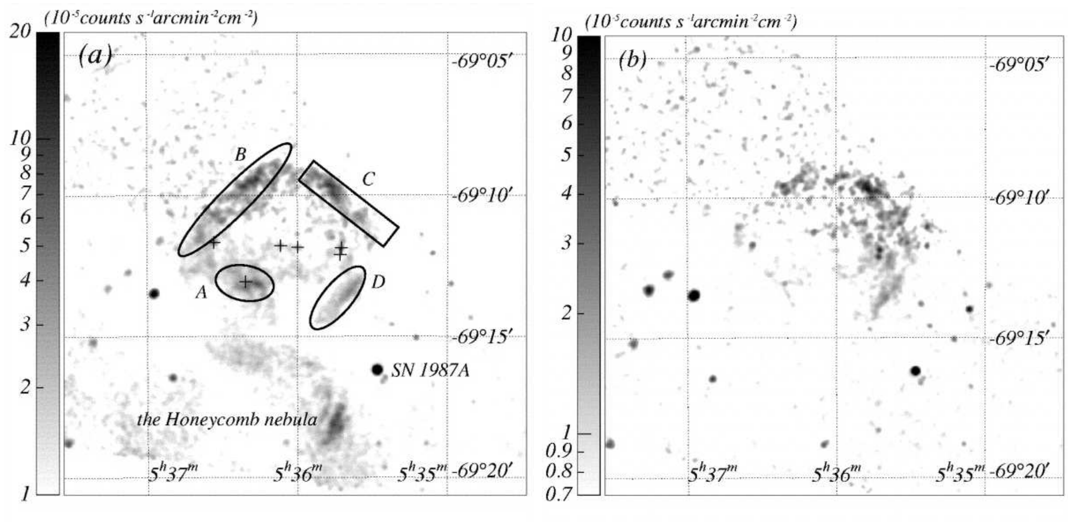

FIGURE 1. Chandra X-ray image of 30 Dor C in the 0.7-2.0 keV band (left) & 2.0-7.0 keV band (right) from [2]. The various regions depicted were chosen for separate spectral Chandra analyses.

Crab-like plerion PSR B0540-69 [16] and also the SNR N157B [20].

H.E.S.S. OBSERVATIONS

Details of the H.E.S.S. telescopes and their performance may be found in [9]. Briefly, H.E.S.S. employs the ground-based Stereoscopic Atmospheric Cherenkov Imaging Technique, and is sensitive to γ-rays of energy $E > 100$ GeV. H.E.S.S. observations of SN1987A were carried out using a 3-telescope system in November and December of 2003, yielding a total 3.44 hours accepted (8 runs) for analysis. Trigger problems with one telescope (CT3) meant that only images from only two (CT2 and CT4) could be used for analysis. SN1987A culminates at a relatively low altitude ($\sim 45^\circ$) giving an estimated energy threshold of 0.55 TeV for these observations (assuming a Crab-like spectrum).

Selection of γ-ray-like events is achieved with several *a-priori*-selected cuts on image shape and reconstructed direction. Shape cuts are based on the Cherenkov image *width* and *length* (mean-reduced-scaled-width MRSW, mean-reduced-scaled-length MRSL; see Benbow et al. [3] for cut details). The directional cut is made on the angular difference between nominal and reconstructed directions θ. The cut $\theta < 0.141^\circ$ is appropriate for point sources and is used for these analyses. The Cosmic-Ray (CR) background is estimated using three different methods, namely the ring, template, and '7-positions' background models were used. The ring model here employs a ring of radius 0.7° surrounding the source region. The ring width is chosen to achieve a ring to source area ratio of 7:1. A correction is applied to the ring normalisation to account for acceptance differences between the ring and source regions. The template background model [17] employs events from a MRSW regime containing no γ-rays [2.0,5.0] and

TABLE 1. Summary of statistics at the nominal SN1987A (SIMBAD) position. The statistical significance S is estimated using Eq. 17 of [12] using a normalisation α.

Backgnd. model	Events ON	Events Backgnd.	α	S	Excess	Excess/hour
Template	124	546	0.182	**+2.2**	24.7	7.2
7-positions	124	761	0.143	**+1.3**	15.3	4.4
Ring	124	598	0.166	**+2.2**	25.9	7.2

corrections are applied to the template normalisation to account for differences in radial and zenith-correlated acceptances. In both models the corrections are applied event-by-event. A third background model employs seven control regions '7-positions' mirrored though the tracking position of each run. Such positions have the same acceptance as that of the source region and so no corrections are necessary. Event statistics at the SN1987A position using these background models are given in Table 1. A significance +1 to +2σ depending on the background position, is noticed at the SN1987A position.

To search for γ-ray emission over the field of view, *skymaps* of excess significance over grid of test nominal positions were generated. Skymaps employing the ring and template models covering a $2°x2°$ FoV centring on SN1987A are presented in Figs. 2 and 3. The ring and template background models invoke somewhat different systematic effects and their comparison helps to establish the robustness of any excesses seen over the FoV. A number of marginally significant (pre-trial) features neighbouring SN1987A are in fact visible in both skymaps. The regions around the 30 Dor C shell (between SN1987A and N157B) and also adjacent to LMC X-1 yield excess significances of order +3σ or greater.

DISCUSSION

The H.E.S.S. upper limit (99% c.l.) on the TeV flux F for SN1987A for $E > 3$ TeV at $F < 6.91 \times 10^{-13}$ ph cm^{-2} s^{-1} can be compared with flux predictions [4], and also with previous measurements made in 2001 by CANGAROO [6, 11] (Fig. 4). The π°-decay model of [4] discusses the light curve of SN1987A up the point where the SN shock is expected to reach the circumstellar ring (2004$\pm$2 yr). [7] and [10] have also earlier discussed TeV emission.

Of the other neighbouring objects in the FoV, the non-thermal X-ray shell of 30 Dor C is one likely site for TeV γ-ray emission and may be an indicator of particle acceleration to multi-TeV energies in the region. The extended positive feature to the East of SN1987A at significance $> 3\sigma$ is located in this region. Note that due to trial factors however such features in the skymaps would not be considered as convincing evidence for TeV emission from these data alone. Further observations by H.E.S.S. of this region in 2004/2005, with a full 4-telescope system would be necessary to confirm these results.

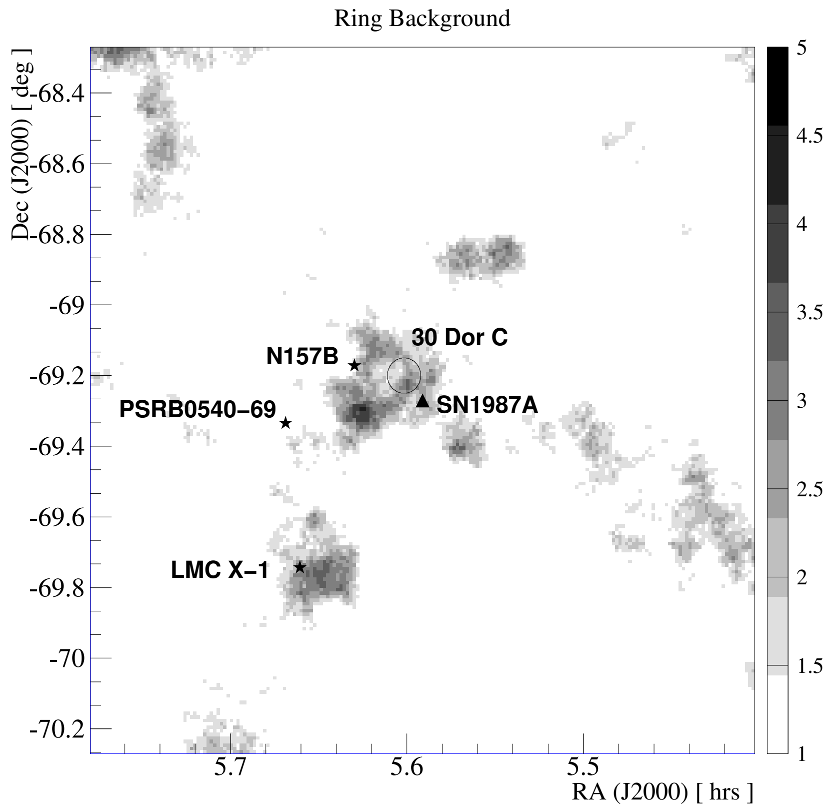

FIGURE 2. Significance skymaps of the SN1987A region (2°x2°) using the Ring background. Only significances above +1.0σ are shown. The black triangle depicts the SIMBAD-defined position for SN1987A. Other interesting objects are also depicted with the black circle indicating the approximate circumference (radius 3 arcmin) of the 30 Dor C X-ray shell. The distributions of skymap significances is fitted with a Gaussian profile with $\mu = -0.058 \pm 0.006$, σ=1.091±0.004.

ACKNOWLEDGMENTS

The support of the Namibian authorities and of the University of Namiba in facilitating the construction and operation of HESS is gratefully acknowledged, as is the support by the German Ministry for Educations and Research (BMBF), the Max Planck Society, the French Ministry for Research, the CNRS-IN2P3 and the Astroparticle Interdisciplinary Programme of the CNRS, the UK Particle Physics and Astronomy Research Council (PPARC), the IPNP of the Charles University, the South African Department of Science, 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 for the construction and operation of the equipment.

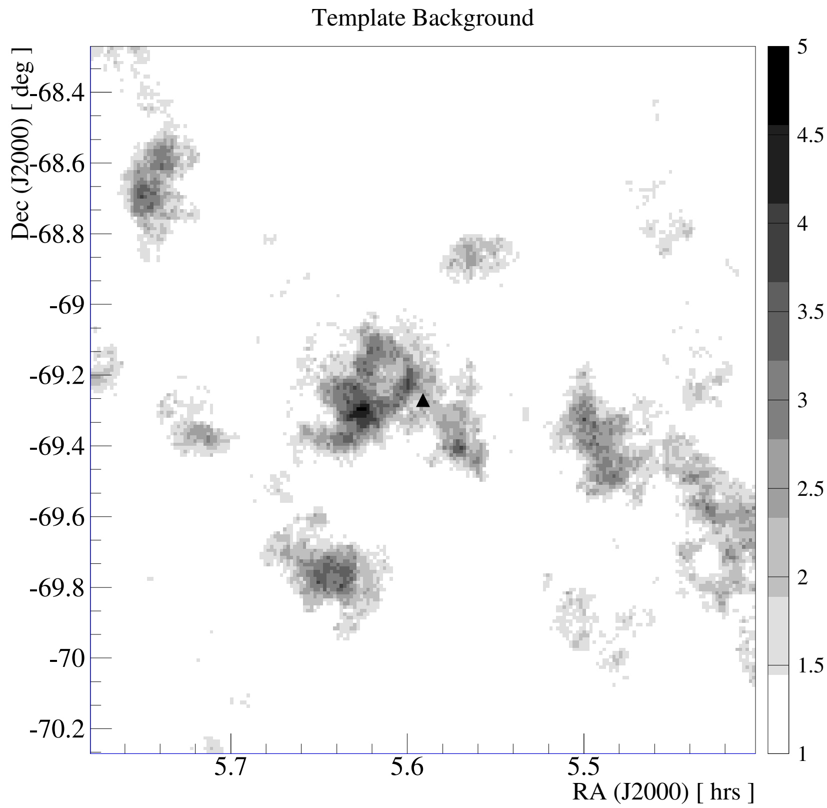

FIGURE 3. As for Fig. 2 but using the Template background model. The distribution of skymap significances is fitted with a Gaussian profile with μ=0.226±0.006, σ=1.078±0.004

REFERENCES

1. Aschenbach B. et al. 2002 in Proc "Neutron Stars, Pulsars, and Supernova Remnants." MPE Report 278. `astro-ph/0208492`
2. Bamba A. et al. 2004 ApJ 602, 257
3. Benbow et al. 2004 Heidelberg Symposium *these proceedings*
4. Berezhko E.G., Ksenofontov L.T. 2000 Astron. Lett. 26, 639
5. Dennerl K., Haberl F., Aschenbach B. et al. 2001 A&A 365, L202
6. Enomoto R. et al. 2003 ApJ 591, L25
7. Gaisser T.K. et al. 1989 ApJ 479, 845
8. Hasinger G. et al. 1996 A&A 312, L9
9. Hinton J. et al. 2004 New Astron. Rev. 48, 331
10. Kirk J., Duffy P., Ball L. 1995 A&A 293, L37
11. Ksenofontov L.T. et al. 2004 New Astron. Rev 48, 485
12. Li T., Ma Y. 1983, ApJ 272, 317
13. Manchester R.N. et al. 2002 PASA 19, 207
14. Park S. et al. 2002 ApJ 567, 314
15. Park S. et al. 2003 `astro-ph/0308220`
16. de Plaa J., Kuiper L., Hermsen W. 2003 A&A 400, 1013
17. Rowell G.P. 2003 A&A 410, 389 `astro-ph/0310025`
18. Rowell G., Hinton J., Benbow W. et al. 2004 *Poster presented at the Heidelberg Gamma Symposium July 2004*

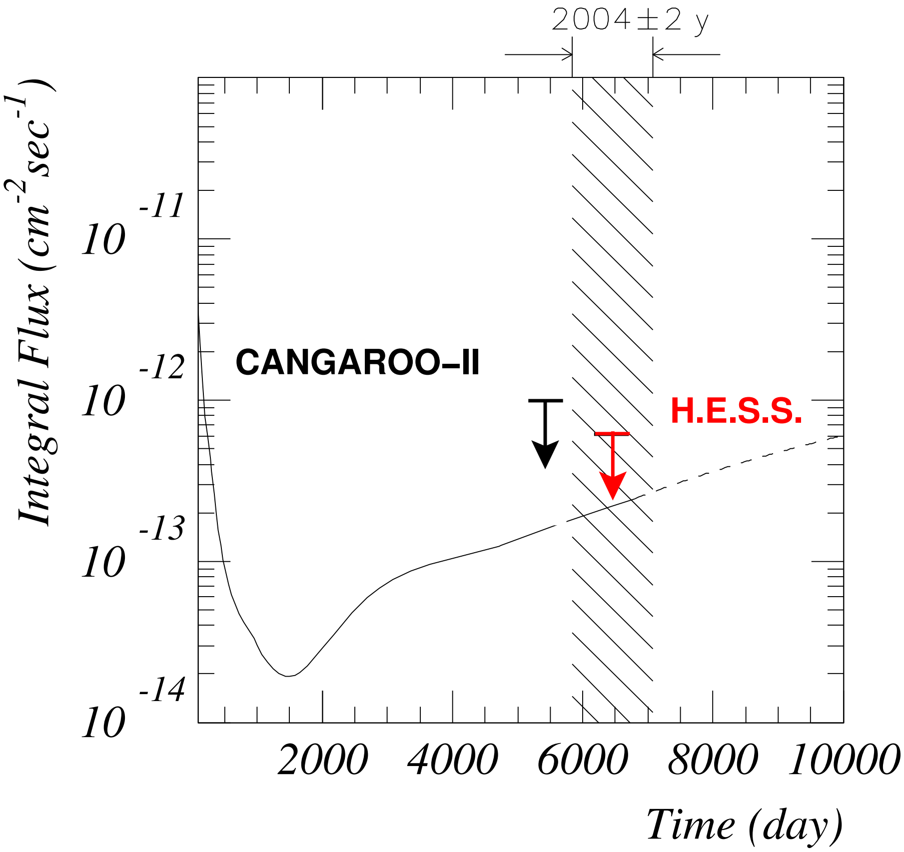

FIGURE 4. Comparison of the predicted SN1987A light curve vs. days since the SN (Integral flux for $E > 3$ TeV) [4] with available upper limits from CANGAROO-II [6] and this work (H.E.S.S.). The predicted light curve is based on a π°-decay model [4] with the hashed region depicting the epoch when the SN shock is expected to reach the dense circumstellar ring. The original plot is adapted from Fig.3 of [6].

19. Ueno M. et al. 2002 Proc "The Universe Viewed in Gamma-Rays" Kashiwa, Japan, 311
20. Wang Q.D. et al. 2001 ApJ 559, 275