Search for TeV gamma-rays from the remnant of SN 1987A

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Abstract

We searched for TeV gamma-rays from the remnant of SN 1987A around 5400 days after the supernova. The observations were carried out in 2001, from November 16 to December 11, using the CANGAROO-II Imaging Atmospheric Cherenkov Telescope. The detection threshold was estimated to be 1 TeV, due to the mean zenith angle of 39°. The upper limits (ULs) for the gamma-ray flux were obtained and compared with the previous observations and theoretical models. The observations indicate that the gamma-ray luminosity is lower than 10^{37} ergs s^{-1} at ~ 10 TeV.

Key words: supernovae: individual (SN 1987A), gamma rays: observations

1 Introduction

The explosion of SN 1987A on February 23, 1987, in the Large Magellanic Cloud, was detected at almost all wavelengths of the electromagnetic spectrum (see, e.g., (15) and references therein). After a weakening of the emission, in accordance with the standard lightcurve for a core collapse supernovae of Type II, at present it shows a continuous increasing brightness in radio (14) and X-ray bands (16). Although observational efforts in the high-energy gamma-ray region were intensively carried out for several years (17; 9; 6; 7; 8; 1; 2; 18; 21), no signals were obtained, except for the possible 2-day TeV gamma-ray burst (7).

The CANGAROO-II telescope is located near Woomera, South Australia. Technical details are presented elsewhere (19), and its performance is described in (11).

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2 Observations and Results

SN 1987A can be seen at a zenith angle of 38° at its culmination. After removing the cloudy periods we selected 708 min. of ON- and 1019 min. of OFF-source data. The procedures and further details of the analysis can be found in (13). We carried out a shower image analysis using the standard set of image parameters, *distance*, *length*, *width*, and α (12), combining the *length* and *width* (after an initial *distance* cut) to assign the likelihoods to each event (10). The likelihoods for both gamma ray and cosmic ray origin were calculated. The cut that was used to reject background events was based on the ratio of these two likelihoods. After these cuts, the image orientation angles (α) were obtained. A gamma-ray signal would appear as an excess at low α after the normalized OFF-source α distribution is subtracted from the ON-source distribution. No statistically significant excess of events with $\alpha < 15°$ was observed.

We obtained 2σ ULs at various threshold energies. The derivation of the integral flux depends on the unknown energy spectrum of the incident gamma-rays. We tried three power-law energy spectra ($E^{-\gamma}$) with differential flux power-law indices $\gamma = 2.0$, 2.5, and 3.0 in Monte Carlo simulations in order to determine the corresponding effective area of the observations. In all cases, the energy ranges of the generated gamma-rays were 0.15–20 TeV. Although the threshold energies varied as expected with initial power-law indices, the spectral responses roughly agreed with each other. We therefore adopted $\gamma = 2.0$, plotted in Fig. 1 (left panel) by the dotted line with arrows, together with the previous measurements and model prediction by (4) (solid line), which correspond to a time of $\sim$5000 days.

3 Discussion

The ULs of this observation are significantly better than those of previous observations. In particular, at 3 TeV it is a factor of 20 lower than that of (7). At 1 TeV, the UL is tightened by a factor of 3, and at the highest point (several TeV) it is improved by a factor of 50. Previous measurements calculated typical luminosity UL of several times 10^{38} ergs s^{-1}, using a distance of $\sim$50 kpc. This observation indicates that the TeV gamma-ray luminosity is lower than 10^{37} ergs s^{-1} at $\sim$10 TeV, which is now of a similar order to those in bright high-energy astronomical objects at various wavelengths.

The lightcurve of soft X-rays, which are expected from the interaction of the supernova shock with the matter, can be well fitted with a t^2 relation (3). The recent X-ray data points tend to exceed the t^2 best fit (3; 16). One can expect

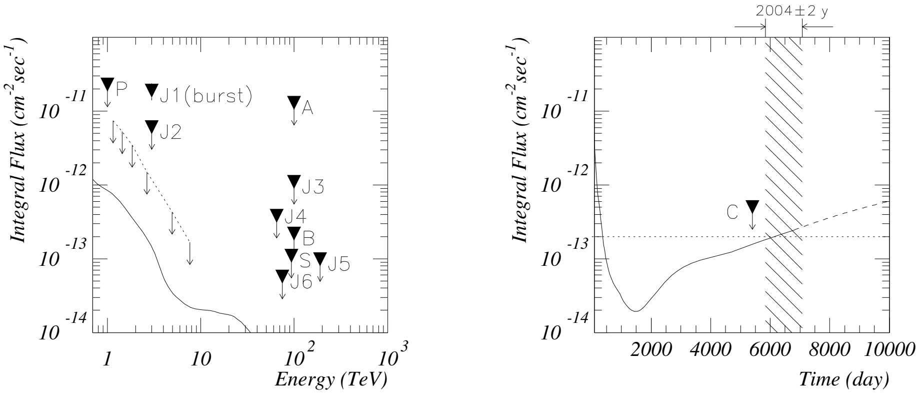

Fig. 1. Left panel: ULs on the flux of gamma-rays. The dotted line with arrows is that obtained by this experiment. P: (17); J1–6: (6; 7; 8; 1; 2); A: (9); S: (18); B: (21). The solid line is theoretical prediction of the flux by (4). Right panel: Flux of gamma-rays with energy $E > 3$ TeV vs. time since the SN 1987A explosion. The current work UL(C) is shown. The solid curve was extracted from (4). The dashed curve is an extrapolation to the solid one. The time when the shock is expected to encounter the inner optical ring is the hatched region. The dotted line is the estimated upper value of gamma-ray flux from 30 Dor C.

the similar behavior of the TeV gamma-ray flux from collisions of accelerated cosmic rays with the ambient matter.

Fig. 1 (right panel) shows the dependence of the gamma-ray flux with an energy > 3 TeV on time since the explosion. The solid line is extracted from the results of numerical calculations by (4). The dashed curve is an extrapolation to that curve under the assumption that $F_\gamma \propto t^2$, which is a reasonable lower limit of the expected flux in the future. One can see that the our UL is just a factor of 3 above the theoretical prediction for the current epoch. At the current rate of expansion, the shock will encounter the much denser inner optical ring in the year 2004±2 (14). Thus, one can expect a dramatic increase also of the TeV gamma-ray flux, which could well exceed the current ULs.

Recently in the Chandra observation in the close vicinity of SN 1987A ($\sim 0.1^\circ$ to the North) a non-thermal X-ray shell-like source at 30 Dor C has been found (20). It is argued, that it is a supernova remnant with the synchrotron X-ray dominated shell. The total luminosity of the non-thermal X-rays is estimated at 6×10^{35} ergs s^{-1}. This is about 10 times larger than that of SN 1006 (20). Let us assume, that in both cases (SN 1006 and 30 Dor C) magnetic field is the same and gamma-ray fluxes are due to the inverse Compton emission, then one can roughly estimate the espected integral flux of gamma rays from 30 Dor C at 2×10^{-14} $cm^{-2}s^{-1}$ at 3 TeV. It is also possible, that the gamma-ray fluxes are due to the nucleonic cosmic ray interactions with the ambient matter. If we suppose that the ISM number density around 30 Dor C is 10 times higher than that of around SN 1006, then the flux can be estimated at 2×10^{-13} $cm^{-2}s^{-1}$. This value is drawn on Fig. 1 (right panel) by the dotted line as a possible upper value of gamma-ray flux from 30 Dor C. One can expect that it to be comparable with the predicted flux from SN 1987A. To distinguish this two sources the observations with angular resolution less than 0.1° will be necessary, which can be done with near future stereoscopic observations; or if the increase of gamma-ray flux in time will be observed, it will mean that the flux is unambiguously from SN 1987A.

The next generation of southern hemisphere IACTs, CANGAROO-III and H.E.S.S., with improved sensitivities, reduced energy thresholds and better angular resolution will have a good chance of detecting a signal from SN 1987A. Regular observations over the next decade are highly desirable.

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