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# Constraints on the SNR origin of cosmic rays from gamma-ray observations in the TeV region

**K. Mizutani and T. Utsugi**

Department of Physics, Saitama University, Saitama 338-8570, Japan

**Abstract.** If shell-type supernova remnants (SNRs) are the acceleration site of cosmic rays in the energy region of less than at least 100 TeV, the associated interactions should result in a detectable flux of gamma-rays in the TeV region for each of nearby these SNRs. Many searches for gamma-ray emission have been performed with imaging Čerenkov telescopes and air-shower arrays in the sub-TeV and/or supra-TeV regions. However, most of measurements failed in observations of significant emission. We set the flux limits on gamma-ray emission from nearby SNRs in the TeV region by using these data. These results constrain model predictions of diffusive shock acceleration of cosmic rays in the shell-type SNRs.

## 1 Introduction

It has been generally believed that shell-type supernova remnants (SNRs) are the site of acceleration of cosmic rays with the energy of less than at least 100 TeV. According to the model of diffusive shock acceleration, it is possible to convert efficiently the kinetic energy of supernova explosions into cosmic rays with the energy up to at least 100 TeV and to explain the energy density of galactic cosmic rays. If cosmic rays are accelerated in shell-type SNRs, then high energy gamma-rays induced by neutral pions are also produced as the cosmic rays interact with ambient matter [1,2]. While the presence of an additional flux of gamma-rays would be also considered from Inverse Compton scattering with ambient photons and bremsstrahlung in matter by high energy electrons in the same energy region. A nearby shell-type SNR at a distance of less than 2 kpc should have the gamma-ray luminosity detectable with ground-based imaging Čerenkov telescopes and air-shower arrays in the sub-TeV and supra-TeV regions. Many measurements therefore have been so far performed with ground-based detectors.

*Correspondence to:* K. Mizutani
(mizutani@cr.phy.saitama-u.ac.jp)

In the present paper is discussed the model of diffusive shock acceleration of cosmic rays in shell-type SNRs by inferring from those measurements in the sub-TeV and supra-TeV regions.

## 2 Measurements

So far several positive observations of gamma-rays from shell-type SNRs, have been made with imaging Čerenkov telescopes in the sub-TeV region. The gamma-ray flux from the northwest rim of SN1006 measured by the CANGAROO group [3] is higher than the expected value assuming the model of diffusive shock acceleration. By comparing with the X-ray flux, which is interpreted as synchrotron emission from high energy electrons, from the same rim measured with the ASCA [4], these gamma-rays would be considered to be Inverse Compton photons scattered by electrons. Therefore there is no evidence of hadronic cosmic-ray acceleration in the rim of SN1006. The gamma-ray flux from the SNR RXJ1713.7-3946 measured by the CANGAROO group seems to be in a similar situation [5]. The gamma-ray emission from the SNR Cassiopeia A is detected in a lower level than the prediction for hadronic cosmic-ray acceleration in the TeV region by the HEGRA collaboration [6].

Pioneering measurements of the TeV gamma-ray flux from six nearby SNRs, IC443, $\gamma$-Cygni, W63, W44, W51 and Tycho, were performed with the Whipple imaging Čerenkov telescope [7]. However no significant emission was detected and upper limits on the sub-TeV flux were reported.

Recently, the Tibet air-shower array has been much improved and the detectable flux level has reached into the predicted one of hadronic cosmic-ray acceleration for a nearby SNRs at a distance of less than 2 kpc. The angular resolution and the energy determination method with the air-shower array have been confirmed by observing the darkness and the shift of the center of the moon's shadow casted in the cosmic-ray flux. Therefore highly unambiguous measurements of multi-TeV gamma-rays have been realized by using the air-shower array because of highly decreasing of systematic uncertainties. This air-shower array is suitable for measurements of gamma-rays from many sources since this is observing day and night at about 1 sr aperture.

The Tibet AS$\gamma$ Collaboration has measured multi-TeV gamma-rays from sixteen nearby shell-type SNRs which are located within 5 kpc and younger than $10^4$ years. No excellent excess has been found and upper limits on the multi-TeV flux have been set for each of sixteen SNRs. Piled up the data of seven nearby SNRs, Cygnus Loop, G65.1+0.6, HB21, IC443, Monoceros, $\gamma$-Cygni and W63, located within 2 kpc distance, the gamma-ray flux upper limit from a SNR of 1 kpc distance has been set to be $4.6 \times 10^{-13}$ cm$^{-2}$ s$^{-1}$ above 3 TeV.

The EAS-TOP, the CYGNUS and the CASA-MIA groups also reported upper limits on the flux in the 10 TeV and 100 TeV regions from nearby SNRs by using air-shower array [8,9,10].

## 3 Discussion

For individual nearby SNRs, the Whipple measurements constrained model predictions of hadronic cosmic-ray acceleration in the sub-TeV region. By comparing with the predictions, the ratio of upper limits on the flux above 0.3 TeV to the predictions are 0.87 and 0.89 for the SNR IC443 and the $\gamma$-Cygni SNR, respectively, where the predictions are derived on the assumption that the efficiency for converting the kinetic energy of the supernova explosions is to be 15%, the spectral index is to be 2.1 and the maximum energy of protons is to be 100 TeV respectively.

The Tibet measurements also have constrained the predictions for emission from nearby SNRs in the multi-TeV region. The ratio of the upper limit on the flux above 3 TeV to the prediction on the same assumption as the described above is 0.26 for the SNR HB21.

The piled-up data of the Tibet measurements much strongly constrain predictions. The ratios of upper limits on the flux above 3 TeV and 10 TeV to the predictions are 0.14 and 0.57, respectively. Out of seven SNRs five are located at about 1 kpc distance. If these SNRs measured are considered to be typical of SNRs, then the maximum cosmic-ray energy of about 100 TeV should have been obtained and the piled-up data should indicate a positive excess. Since the flux from several SNRs measured with the EGRET in the sub-GeV and multi-GeV regions seems to be consistent with model predictions of hadronic cosmic-ray acceleration, it seems that upper limits on the multi-TeV flux may imply a steeper power-law spectrum of cosmic rays in SNRs. However a model modification, such as the reacceleration model, would be required.

According to the model of diffusive shock acceleration, the allowed region of the conversion efficiency of supernova explosions ranges from 10% to 30% and the spectral index of the gamma-ray spectrum in SNRs from 2.1 to 2.7. The kinetic energy of the supernova explosion and the density of ambient matter range also widely. Those values used in the predictions would be appropriate for the estimation of gamma-rays from an average shell-type SNR. Assuming that shell-type SNRs would supply all the energy density of galactic cosmic rays, the luminosity of gamma-rays induced by hadronic cosmic rays in the multi-TeV region depends mainly on the frequency of supernova explosions and the effective time for cosmic-ray acceleration. Therefore so far as the estimation of these values is considered to be suitable, the evaluation of the luminosity of shell-type SNRs would not be much changed. Another site of cosmic ray acceleration besides shell-type SNRs might be required by the data on gamma-ray flux in the sub-TeV and multi-TeV regions.

The Tibet air shower array would be improved further in 2002. A clear evidence or strong constraint on hadronic cosmic-ray acceleration in shell-type SNRs would be expected by using the improved air-shower array in the near future because the statistics would become much better and the angular resolution would be improved.

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