# Gamma-ray study of the W44 region with *Fermi*-LAT

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***Abstract*. Supernova remnants (SNRs) have been prime candidates for production sites of Galactic cosmic rays. Among them, those interacting with molecular clouds are good targets for the Large Area Telescope (LAT) aboard the *Fermi Gamma-ray Space Telescope*, since GeV gamma rays can be expected through neutral pion decays resulting from interactions between accelerated protons and cloud gas. Observations by the *Fermi*-LAT are expected to confirm or reject the hypothesis that cosmic-ray protons are accelerated at SNRs. Recent observations by *Fermi*-LAT have revealed the morphological and spectral characteristics of GeV gamma-ray emission from the W44 region, where it is known that the SNR shell is interacting with molecular clouds. Here we report on *Fermi*-LAT results of the W44 region.**

***Keywords*: gamma rays, *Fermi Gamma-ray Space Telescope*, supernova remnants**

## I. INTRODUCTION

Diffusive shock acceleration (e.g. [1]) at shocks of supernova remnants (SNRs) has been thought to be responsible for the production of Galactic cosmic rays. Nonthermal emission from SNRs, which works as probes of accelerated particles, has been observed extensively in wide range of wavelengths, from radio to gamma rays. In the very-high-energy (VHE) gamma-ray domain, recent atmospheric Cherenkov telescopes, with their high sensitivities and modest angular resolutions, provided us with detailed information about morphological and spectral characteristics of emission from several SNRs (e.g. [2], [3]). Next breakthrough is expected in the high-energy (HE) gamma-ray region, where the Large Area Telescope (LAT) on the *Fermi Gamma-ray Space Telescope* [4] explores.

W44 (also known as G34.7$-$0.4) is one of the SNRs that one can expect HE emission, since the EGRET on the *Compton Gamma Ray Observatory* detected HE emission in the vicinity of the SNR [5]. Although the 95% confidence region of the EGRET source, 3EG J1856+0114, is consistent with the southern portion of W44, the limited statistics and detector sensitivity of the EGRET did not allow detailed spectral and morphological study of this region. In the VHE region, no detection is reported so far [6], [7], [8]. This suggests that the 3EG source has a spectral cutoff between the GeV and TeV energies since the EGRET detected quite hard spectrum with photon index of $\Gamma = 1.93 \pm 0.10$ [9].

W44 is classified as a mixed-morphology SNR with its shell-type shape in radio and centrally peaked thermal X-ray emission. The radio shell structure is elongated from the northwest to the southeast. and has an extent of $\sim 35' \times 26'$ (see e.g. the 1442.5 MHz image by [10]). The X-ray emitting region is confined in the radio shell structures and no emission is detected from the shell [11], [12]. A radio pulsar ($P = 267$ ms), PSR B1853+01, was discovered about $9'$ south of the geometric center of the SNR [13]. The characteristic age and distance of the pulsar are estimated as $2 \times 10^4$ yr and $\sim 3$ kpc, both of which are consistent with those estimated for the SNR itself. A pulsar wind nebula (PWN) associated with the pulsar is also found in radio and X-rays [14], [15], [16]. The PWN seen in radio extends $\sim 2'$ to the north of the pulsar [14] while the extent is about the half in X-rays [16].

The SNR is of particular interest since it is known to be interacting with molecular clouds, which gives us important clues to conjecture the gamma-ray emission mechanism. Based on the $^{12}$CO line observations, it was revealed that the giant molecular cloud CO G34.8$-$0.6 is interacting with W44 on the eastern side of the SNR [17], [18]. They also detected high-velocity ($> 25~\mathrm{km~s^{-1}}$) CO line wings which are confined to compact ($\approx 1.5$ pc) spots and are located adjacent to bright radio filaments or knots, providing another evidence of the SNR-cloud interaction [18]. Yet another evidence for the interaction is provided by near- and mid-IR observations, which traces shocked $\mathrm{H_2}$ [19], [20]. The mid-infrared emission at $4.5~\mu\mathrm{m}$ is found to be bright especially in the northern and southwestern parts of W44 and shows good agreement with the radio morphologies there [20], [21].

## II. OBSERVATION & DATA REDUCTION

The *Fermi Gamma-ray Space Telescope*, launched on 2008 June 11, started continuous survey-mode observation on 2008 August 4. The LAT, with its wide field-of-view (FoV) of 2.4 sr, observes the whole sky in every $\sim 3$ hr (2 orbits) in this mode. Besides the wide FoV, the LAT has better detector performance than the past detectors, the large effective area of $\sim 8000~\mathrm{cm^2}$ (on axis at 1 GeV) and point spread function (PSF) better than $1.0^\circ$ (for 68% containment) at 1 GeV.

Here we analyzed the *Fermi*-LAT data taken for 7 months, from 2008 August 4 to 2009 March 4. The data set was reduced with the standard analysis software package, LAT Science Tools. We only use the "Diffuse class" events, which are those reconstructed with the highest probability of being photons. To reduce the background from the Earth albedo, we eliminated events with earth zenith angle greater than $105°$. For the spectral analysis, we analyzed the events whose estimated energy is greater than 200 MeV and whose reconstructed incoming direction is within $10°$ radius centered on the rough location of W44, $(\alpha_{J2000}, \delta_{J2000}) = (18^h56^m00.0^s, 01°18'00.0'')$

## III. Analysis

Figure 1 shows the *Fermi*-LAT count map of the W44 region above 1 GeV. As seen in this figure, a bright gamma-ray source is detected from the position consistent with SNR W44. This source is one of the sources listed in the Fermi Large Area Telescope Bright Source List, and named as 0FGL J1855.9+0126 [22]. We present in Figure 2 a zoom in view of the W44 region. The green contours are the VLA (20 cm) image taken from the Multi-Arraay Galactic Plane Imaging Survey (MAGPIS) website [23], [24]. Results of detailed morphological study will be presented at the conference.

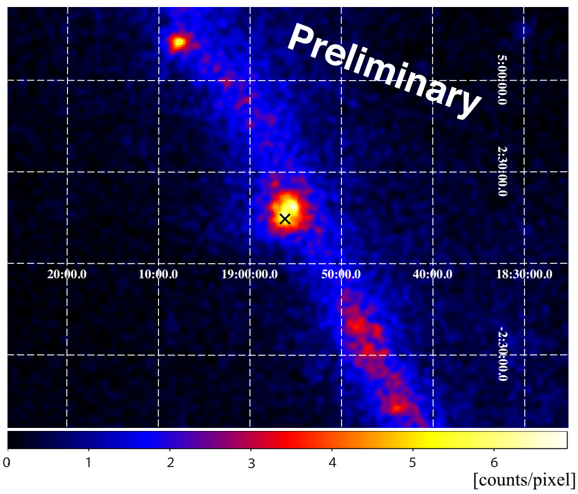


Fig. 1: Smoothed count map of the W44 region obtained with the *Fermi*-LAT above 1 GeV. North is up and east is to the left. The pixel size is $0.05° \times 0.05°$. The black cross indicates the location of PSR B1853+01.

Spectral analysis was performed using the maximum likelihood package, `gtlike`. Our results will be shown at the conference, and the emission mechanism will be discussed based on the results.

## IV. Discussion and Summary

The *Fermi*-LAT detected HE emission from the position consistent with SNR W44. The spatial distribution of the gamma-ray events is significantly extended compared to the PSF of the *Fermi*-LAT. There are at least three possible gamma-ray source candidates in the W44 region, the pulsar PSR B1853+01 [13], the PWN associated with the pulsar [14], [15], [16], and the SNR shell. Careful morphological and spectral studies are required to determine which of them is responsible for

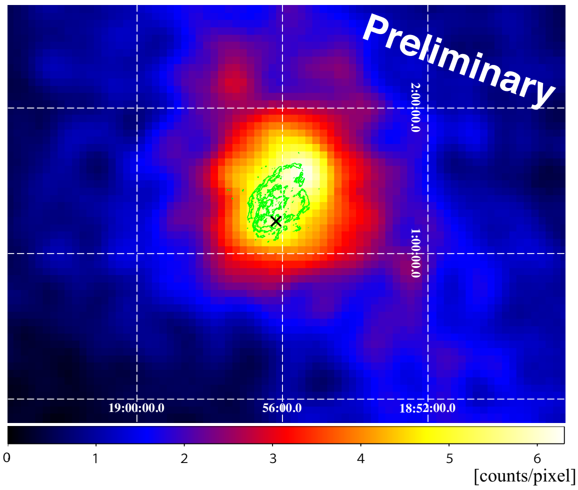


Fig. 2: Zoom in view of the W44 region in gamma-rays above 1 GeV. The contours are VLA (20 cm) image. The black cross indicates the pulsar location.

the observed gamma-ray emission. In addition, data from other wavelength such as radio or VHE gamma-rays should help us to disentangle the the possible emission mechanism. These discussions will be presented in the conference and also in the upcoming paper.

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