Cosmic-ray clouds escaping from the middle-aged SNR W44

Giada Peron[1,2], Sabrina Casanova [2,4], Roberta Zanin [2,3], Felix Aharonian [2,3]

[1]APC, Paris, France [2]MPIK, Heidelberg, Germany, [3] DIAS,Dublin, Ireland [4] CTAO,Bologna, Italy, [4] IFJAN, Krakow, Poland

Motivation

W44 is a well-known middle-aged (∼10000 yr) SNR already detected in gamma-rays, located within a dense cloud complex [1]. Near W44, two gamma-ray sources were unveiled and associated with runaway particles illuminating surrounding molecular clouds [2].

With improved photon statistics, we analyze the remnant and its surroundings and constrain the spectra and their morphology by comparing the emission with high-resolution gas data.

The goal of this work is to understand the origin of gamma-radiation, and to explore the acceleration mechanism of CRs and the character of their escape from the supernova remnant.

Methods

We analyzed Fermi-LAT data in the energy range 100 MeV – 1 TeV. We used standard cuts, the standard galactic and extragalactic background, and the most recent catalog of discrete sources (4FGL). We remodeled the spectrum and the morphology of all sources within 1° from W44;

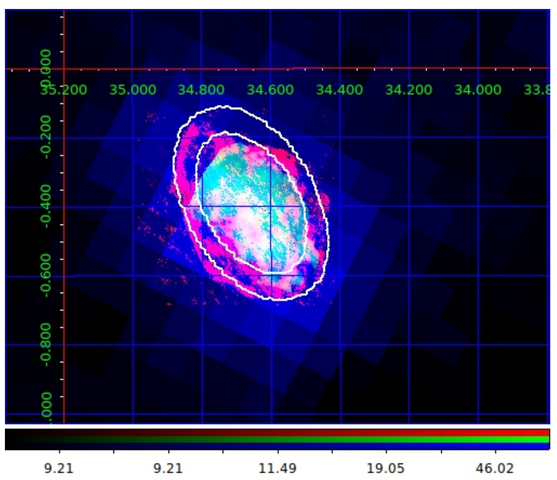
Morphology [> 1 GeV]: using an AIC-based method, we investigated the morphology of the W44 shell and of the surrounding sources.

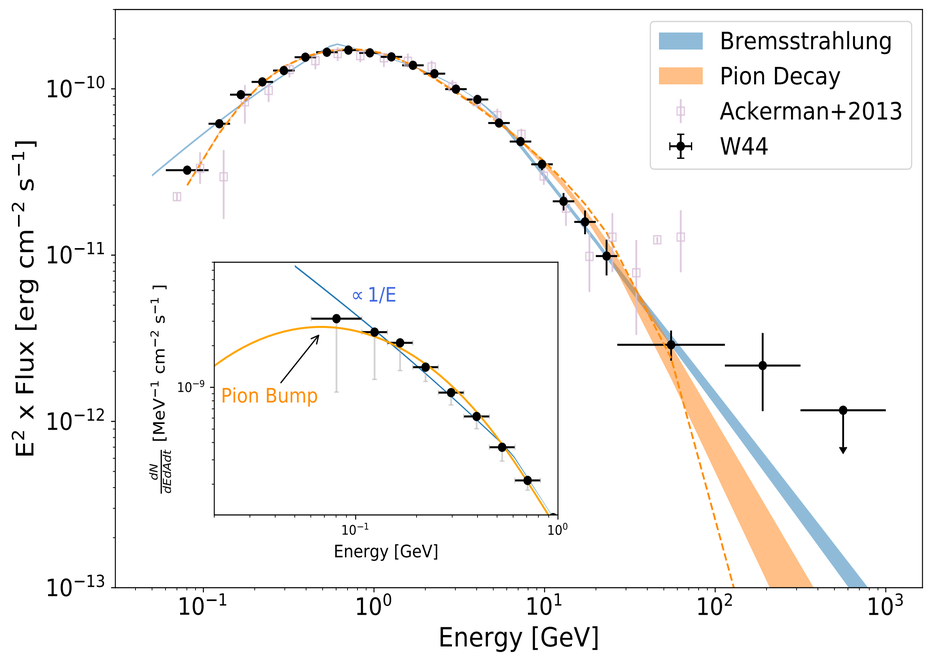
Spectrum [> 100 MeV]: using an AIC-based method, we investigated the spectral shape of the shell.

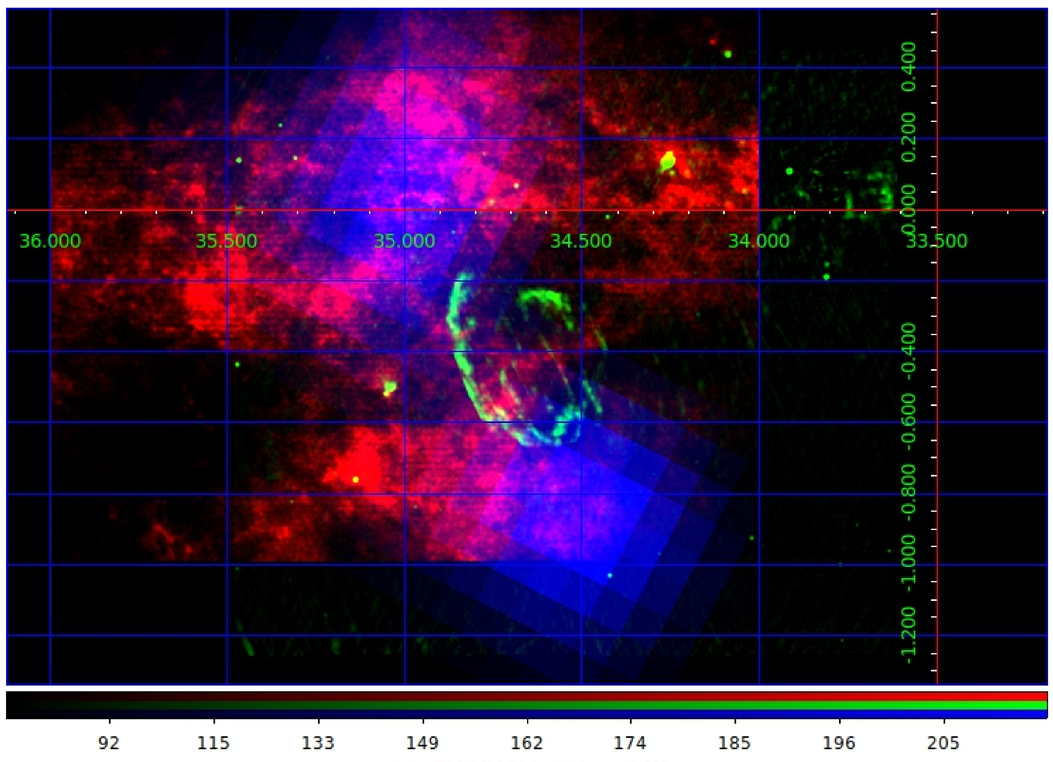
Gas-gamma correlation: We use the high-resolution (1 arcmin) FUGIN CO map [3] to investigate the correlation between γ-rays and gas

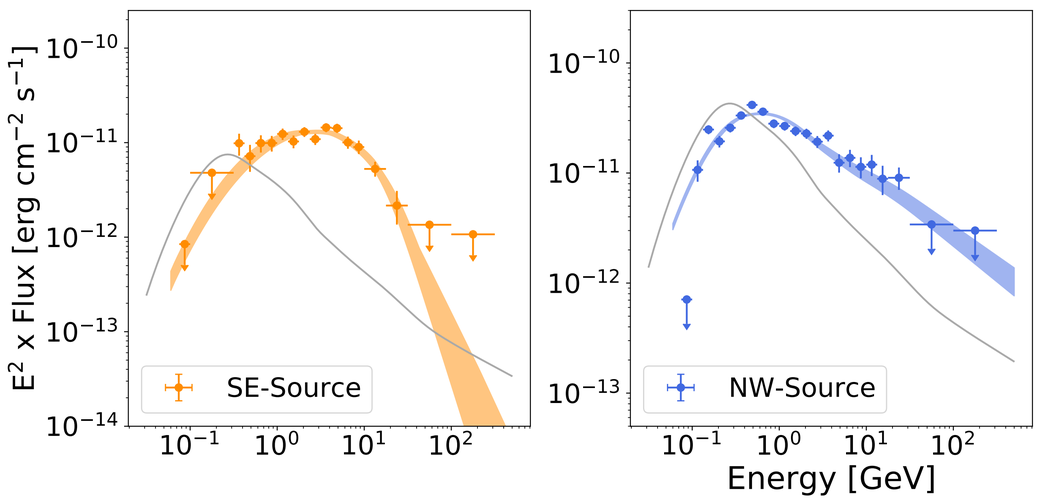
Modelling: We use `naima` [4] to find the best particle distribution.

W44 best morphology: Elliptical ring;









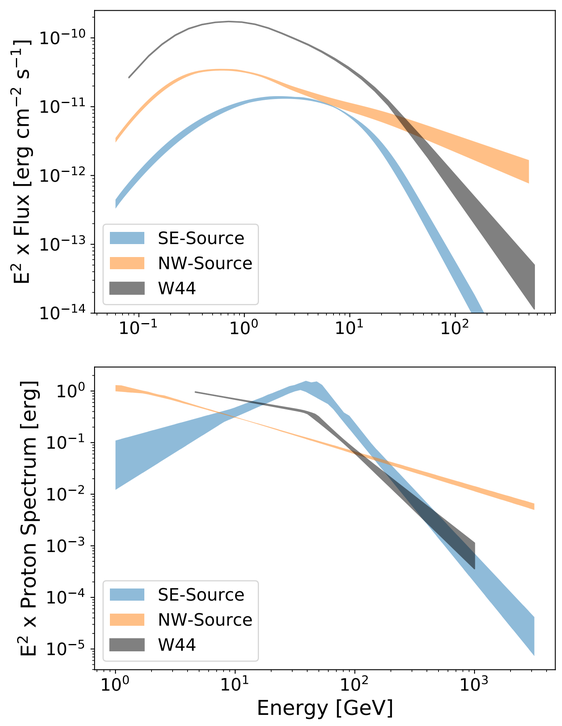
$M_{NW} = 2 \times 10^5\ M_\odot$
$M_{SE} = 0.4 \times 10^5\ M_\odot$

Pion signatures from W44

A bump feature around 1 GeV in the SED is usually associated with pion decay. However, also a low-energy break in the electron spectrum can produce a bump in the spectrum in the case of bremsstrahlung radiation. The latter has a theoretical limitation on the spectral index $\gamma < -1$. We detect a spectrum of index $\gamma = -0.5$ below 1 GeV. The quality of low-energy data collected for W44 below 1 GeV allows us to exclude the bremsstrahlung scenario.

Cosmic-ray Clouds

- Two bright gamma-ray sources emerge near the SNR W44;
- The two sources are located along the magnetic field of the SNR;
- The comparison with the gas does not show a correlation with the gas in the region;
- The clouds have a similar ISM density and a similar distance from the remnant;



Conclusions

- W44 morphology is an elongated shell;
- W44 emission is hadronic;
- CRs escape from W44 anisotropically along the magnetic field (see [5]);
- Runaway CRs agglomerate in two blobs which do not coincide with peaks in gas;

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Contact information:
Giada Peron
giada.peron@mpi-hd.mpg.de

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Max-Planck-Institut für Kernphysik

APC, CNRS, France