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A gamma-ray view of supernova remnants and molecular cloud interactions with H.E.S.S. and Fermi-LAT

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Abstract. Supernovae from massive stars are exploding in giant molecular clouds (MC) and their remnant (SNR) expending in dense material. The physical interaction between SNR and MC can produce OH maser (1720 MHz) emission tracing the shocked surrounding medium. High and very-high energy (HE and VHE) gamma rays have been detected in coincidence with OH maser, SNR and shocked MC. Neutral pions decay is the best model to explain the origin of the gamma-ray emission.
Here will be presented some results of HE and VHE gamma-ray experiments of known cases as W44, W28 and W51C as seen by H.E.S.S. and *Fermi*-LAT to study in an easier way the morphology and the spectra. The very good angular resolution of H.E.S.S. experiment is useful to model the morphology in the GeV range, and the HE spectra is helpful to constrain the gamma-ray origin.

Key words. gamma-ray observations, Fermi-LAT, H.E.S.S. — supernovae: individual (W28, W44, W51) — ISM: molecular cloud, OH masers

1. Introduction

The discovery of particle acceleration at supernova remnant (SNRs) shock is an important suggestion to resolve the Galactic cosmic-ray origin question. Relativistic electron production has been established in X-ray emission coincident with SN 1006 for example by Koyama et al. 1995. In the TeV range, Aharonian et al. 2004 detected gamma-ray emission in the direction of SNR RXJ1713.7–3946. The acceleration of particles up to the "knee" seems to be confirmed. Two main scenarios can explain a γ-ray emission : leptonic or hadronic. The hadronic scenario is typically produced from proton-proton interaction by $\pi^0 \rightarrow \gamma\gamma$ decay. These collisions can take place when SNRs shock is moving through dense clouds (Drury et al. 1994). This is the reason why Montmerle 1979 and Frail et al. 1996 suggested interacting SNRs are interesting candidates to hadronic scenario.

The evolution of the remants depends on the ambient medium. Tycho's SNR is a young remnant (500 yr) with a physical size of $\sim$ 5 pc (see Lee et al. (2004) for distances estimations). If we assume a SNR with this typical size, it correspond to 0.07° at 5 kpc.

The very good angular resolution of H.E.S.S. ($PSF \simeq 0.06°$) allow us to study in detail the morphology of SNRs.

The onboard *Fermi*-LAT telescope lauched in 2008 provides new informations in the discrimination between leptonic and hadronic scenarios in the γ-ray band. Indeed, the LAT covered the energy range 20 MeV - 300 GeV where the spectral difference is clearer.

The molecular clouds have a density between 10^2 and 10^6 cm^{-3} and a temperature around 10 K. Because no radiation from H_2 is easily detectable, the main way to trace clouds is to look for the CO molecule, the most abundant interstellar molecule (Smith et al. 1971). The denser parts of the cloud core can collapse into clumps to form protostars, the whole process takes about 10^6 yr. This means that the association between SNRs and molecular clouds is naturally expected, especially in star-forming regions Montmerle (1979). We can estimate that 10% of SNRs are associated with MC. While in about 80% of cases, SNRs evolves in an environment strongly modified by the precursor (seeDubner's talk at CRISM-2011 2011).

In order to confirm the interacting scenario, the physical association between a SNR and MC is needed. The OH maser (1720 MHz) line is produced by a collisionnal pumping of the OH radical in the MC Wardle et al. (2002). Elitzur 1976 demonstrated the very particular environment required behind the shock. The lines detected are at the edge of the shells because the column density must be large and the coherence of the molecule's velocity as well. Only 10% of the SNRs present this rare phenomena (Hewitt et al. 2009). Several OH maser lines have been detected in coincidence with SNRs W28, W44, and W51.

In this article, we will review three major interacting SNRs which present a coincident OH maser line, molecular cloud and gamma-ray emission from *Fermi*-LAT and H.E.S.S.

2. Gamma-ray emission detected in the region of interacting SNRs

2.1. SNR W44

The whole radio shell of SNR G34.7-0.4 (W44) is visible (Jones et al. 1993). Its distance (2.5 kpc) has been deduced from HI absorption (Cox et al. 1999), and its age estimated between 1.7×10^4 yr and 2×10^5 yr. The detection of 25 OH masers (1720 MHz) (Wardle et al. 2002) and IR filaments tracing the shocked gas (Reach et al. 2005) suggest an interacting scenario. Wolszczan et al. 1991 reported the detection of a pulsar near the center of the shell which seems associated to the remnant.

Figure 1 left presents the *Fermi*-LAT excess detected in coincidence with the shocked gas (green contours) at the boundary of the shell. The spectral data follow an index $\Gamma_1 \sim 2.1$ below the break $E_b \sim 2$ GeV and $\Gamma_2 \simeq 3.0$ above. The observation by H.E.S.S. and other experiments at very high energy (VHE) do not allow to detect any excess in this direction. Nevertheless, the spectral energy distribution (SED) in figure 1 right confirms the hadronic scenario.

2.2. SNR W28

SNR G6.4-0.1 (W28) is also very well known in radio waves (Andrews et al. 1985), X-rays (Nicholas et al. 2010) and gamma-rays by H.E.S.S. and *Fermi-LAT*. This region presents several gamma-ray excesses as shows the *Fermi*-LAT count map (figure 2 left) between 2 and 10 GeV (Abdo et al. 2010). The H.E.S.S. significance contours in black have been reported. The excess called "source N" is coincident with many OH masers Frail et al. (1994); Claussen et al. (1997, 1999), the molecular cloud at the same radial velocity has been studied by Wooten 1981. No other counterparts has been detected.

The shape in GeV range follows an index $\Gamma_1 \simeq 2.1$, the index is steeper ($\Gamma_2 \simeq 2.7$) above a break at $E_b \sim 1$ GeV. TeV index is compatible with Γ_2. The SED modelisation need the radio data to be well constrained. The best explaination of the γ-ray origin is the π^0 decay (see figure 2 right).

2.3. SNR W51C

SNR G49.2-0.7 (W51C) is located in a complex region because of the presence of HII regions and an extended region with SNR-like properties Copetti et al. (1991). Carpenter et al. 1998 associated this complex with a giant MC. Thermal X-ray (Koo et al. 2002), OH masers (Brogan et al. 2002), shocked atomic and molecular gas (Koo et al. 1997) are other proofs of the interaction scenario. The last counterpart known is a pulsar wind nebula

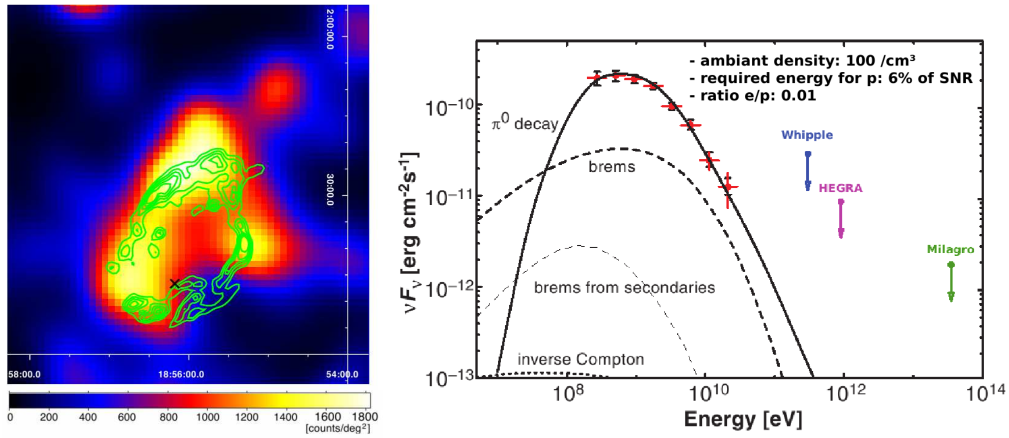

Fig. 1. *Left*: Count map between 2 and 10 GeV from the LAT (background color) in direction of W44. The γ-ray morphology is compatible with the shocked gas (green contours) - *Right*: SED in γ-ray domain. The red points are the LAT data, the upper limits at higher energy are given. Each curve correspond to contribution from each emission process. The π^0 decay (solid) is the dominant process to explain the data.

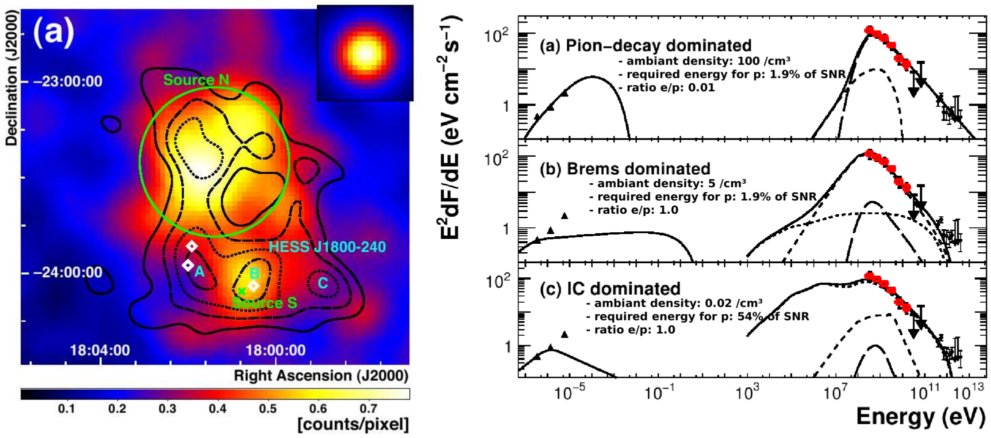

Fig. 2. *Left*: Count map between 2 and 10 GeV from the LAT (background color) from the W28's region. Black contours are the H.E.S.S. significance levels at 20, 40, 60 and 80% of the peak value. - *Right*: SED of the W28 Nothern source. The red points are the LAT data. Each plot shows a different emission dominated process (π^0 decay, Bremsstrahlung and inverse Compton). Radio data are needed to better constrain the model.

(PWN) candidate near the center of the remnant detected by Koo et al. 2005.

Fiasson et al. 2009 discovered an extended VHE gamma-ray emission in coincidence with the PWN and the OH maser. *Fermi*-LAT detected an extended γ-ray emission Abdo et al. (2009).

The spectral shape follow a LogParabola in GeV range (index $\Gamma \simeq 2.1$) and an index $\Gamma \simeq 2.7$ in the TeV range. In order to better constrain the model of the emission scenario, the radio data are required. The hadronic scenario with π^0 decay is the best model even if the morphology is not clear (see figure 3 right).

3. Conclusion

The majority of SNRs are physically associated with dense molecular clouds as shows the detection of OH maser (1720 MHz) lines. It is believed that SNRs are particle accelerators,

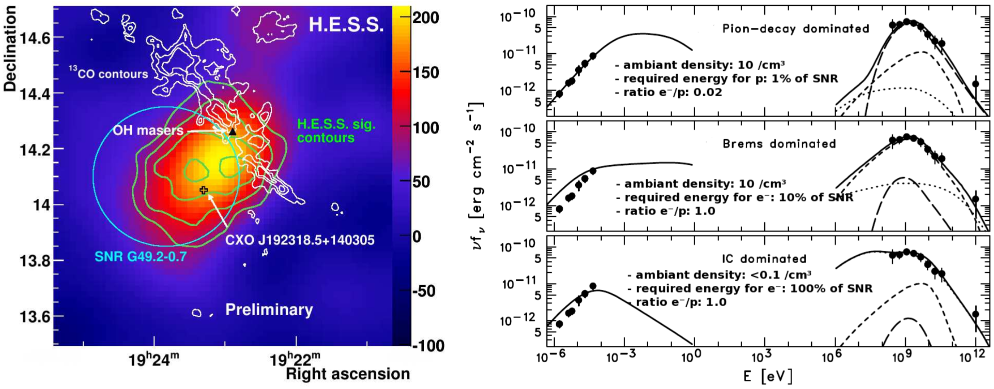

Fig. 3. *Left*: H.E.S.S. excess map of W51's field of view with ^{13}CO contours (white), PWN candidate (open cross), and OH masers (triangle) - *Right*: SED of the emission compatible with W51C. Each plot shows a different emission dominated process (π^0 decay, Bremsstrahlung and inverse Compton). Radio data are useful to constrain the model.

then the interaction between SNRs and MC can play a role in the Galactic cosmic ray production via proton-proton interaction and π^0 decay. The observation with H.E.S.S. and *Fermi*-LAT allow us to precisely study the morphology and the spectrum of the γ-ray emissions. The modelisaitons of the hadronic cases yields broken power law between 100 MeV and 50 TeV. Because the LAT is sensitive to photons between 100 MeV and 200 GeV, the break ($E_b \in [2, 10]$ GeV) in the spectrum can be detected. The mean index for $E < E_b$ is about 2.0, above it the index is between 2.6 and 3.1 up to TeV range. With its good angular resolution, H.E.S.S. can study precisely the morphology of the gamma-ray sources.

The three examples developped in this review, show the major objects in the H.E.S.S. field of view. The study in the whole gamma-ray domain is crucial to understand in details the morphology and the spectrum of these sources because each experiment provides their strong point.

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