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HIGH ENERGY EMISSION IN PULSAR WIND NEBULAE

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Abstract. Pulsar wind nebulae (PWNe) are extended structures of shocked relativistic particles powered by a pulsar at very high energy. Interaction between these particles and the surrounding medium produces very high energy photon emission. Observation by imaging Cherenkov telescopes system in an energy scale from about 100 GeV to 100 TeV, shows various morphologies, depending on many parameters : age, ambiant medium distribution, magnetic fields. The H.E.S.S. experiment allowed to find out many sources, like Vela X or HESS J1825-137, usefull for morphology analysis. Last results obtained with H.E.S.S. and implications on the evolution model of PWNe will be presented here.

Introduction

Pulsar wind nebulae emit in a wide energy range, from radio to TeV γ-rays. Radio and X-ray observations allowed us to discover characteristics about magnetic fields, evolution in pulsar vicinity, as it will be described in the first part. Observing PWNe at higher energy gives new information to explain the complex evolution of these sources et better define their properties.

1 An evolving definition

Thanks to observations in new energy ranges, PWNe definition is evolving, by finding out new properties for each energy range. From the first observations, the following properties were found:

- a filled center or blob like form,
- a flat radio spectrum with a spectral index between 0 to -0.3,
- a well-organized internal magnetic field with high integrated linear polarisation at high radio frequencies.

With the growing accuracy of instruments for X-ray astronomy, the definition of PWNe has been broadened:

- a torus and a jet near the pulsar, and a jet aligned with the pulsar spin axis (see Pavlov et al. 2003),
- evidence for particles re-acceleration between light cylinder and shock radius, providing a hard X-ray spectral index between -1.5 to -2. near the shock,
- evidence for synchroton cooling beyond the shock with spectral index between -2. to -2.5.

Here are only the main properties. A more exhaustive list can be found in de Jager & Djannati-Ataï (2008).

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2 Pulsar Wind Nebulae discovery

The H.E.S.S. experiment has observed the South hemisphere sky since 2003 and found many γ-ray sources like supernovae remnants, active galactic nuclei, pulsar wind nebulae and many other unidentified sources. Some sources of the last type could be associated with a pulsar, with a position offset.
The γ-ray emission from HESS J1912+101 was discovered thanks to the H.E.S.S. galactic survey (Aharonian et al. 2008). This source (Fig. 1) does not show any apparent counterpart in other wavelengths. The best candidates to explain this emission are the supernova remnant 44.6+1.1 (white ellipse on Fig. 1, top-right) in one hand, and the pulsar PSR J1913+1011 on the other hand. In the first case, emission would be due to interaction of accelerated particles with dense molecular clouds. However, X-ray observations do not show any counterpart, which would be expected in this case.

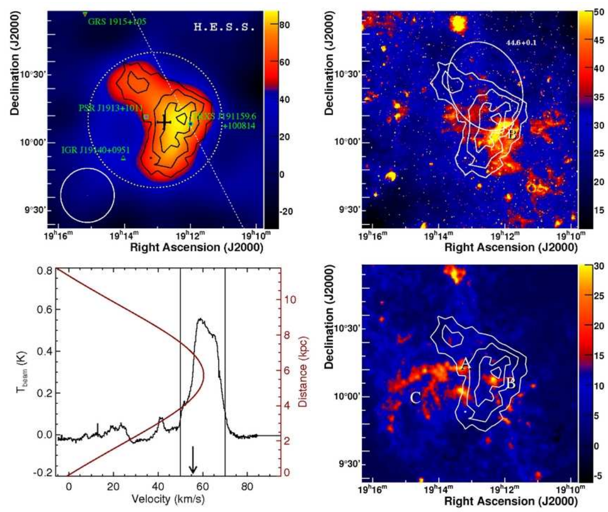

Fig. 1. Top, left: γ-ray excess distribution. Top, right: radio emission using the Spitzer telescope. The region marked as "B" is a complex of molecular clouds and HII-regions. The white ellipse illustrates the position and the extension of the SNR 44.6+0.1. Bottom, left: Velocity profile of ^{13}CO intensity at 110.2GHz. The arrow marks the velocity corresponding to the nominal distance of PSR J1913+1011. Bottom, right: ^{13}CO intensity, integrated in the velocity range 50-70km.s^{-1}

The second candidate can be also the engine of this emission. The shifted position is explained by the proper motion of the pulsar, as it is shown in Fig. 1 (bottom-left). The asymmetric emission, in this case, would be due to molecular clouds, observed with CO line at 110.2 GHz.

3 Morphology analysis

The γ-ray source HESS J1825-137 is a well-known example of energy dependent and asymmetrical morphology emission. It is associated to X-ray PWN G18.0-0.7 and the pulsar PSR J1826-1334. The shifted pulsar position compared to the TeV emission is also explained by an evolution in an inhomogeneous medium : nebula is evolving where the density is lower. This phenomena is confirmed by simulation of pulsar nebula in a nonuniform mdium (Blondin et al. 2001): after a free expansion, the reverse shock collides with the pulsar wind during the Sedov period. An inhomogeneous medium causes an asymmetrical collision and hence an asymmetrical evolution of the PWN.

An other property discovered with HESS J1825-137 is the energy dependent morphology. As shown in Fig. 2 , γ-ray emission is much more extended than X-ray emission. Furthermore, this dependance is also apparent at TeV energy: the source extension increases with decreasing energy (Fig. 4). As a result, the spectrum is softer far away the pulsar position and harder near the pulsar (see Fig. 4). This can be well explained by particles cooling: the older ones, far away, had more time to loose their energy by synchrotron cooling.

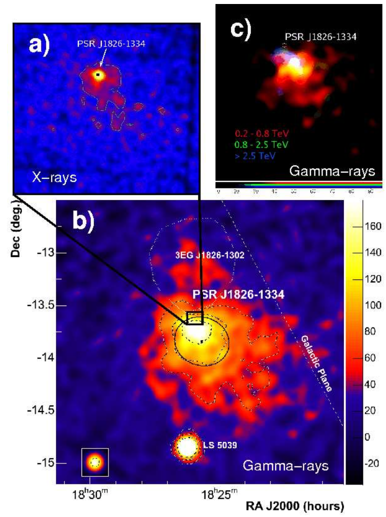

Fig. 2. a)X-ray emission observed with XMM-Newton space-base telescope. b)γ-ray excess map. c) TeV γ-ray excess integrated in 3 energy ranges : 0.2-0.8 TeV (red), 0.8-2.5 Tev (green) and above 2.5 TeV (blue).

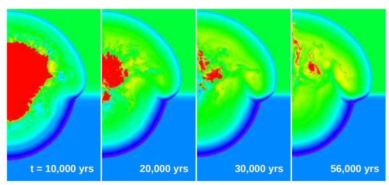

Fig. 3. Simulation of pulsar wind nebula evolution in an inhomogeneous medium (Blondin et al. 2001).

4 Mechanism of emission

High energy emission is mainly due to two mechanisms. The hadronic model describes photon emission as the result of interaction between accelerated protons and cold protons. The leptonic model includes interactions with leptons like synchrotron emission where magnetic density dominates, and Inverse Compton emission, due to interactions between particles and photons from Cosmic Ray Background (CMB), infrared interstellar medium, or synchrotron photon, where radiation density is dominating. In the PWNe case, a purely leptonic model better fits the Crab data (see Fig. 5).
An other example favoring leptonic model is given by VelaX. With the hypothesis of acceleration during the early age of the pulsar, and using the 40ms period of the pulsar, the energy needed for a dominating hadronic emission would be higher than the energy given by the pulsar itself (van der Swaluw & Wu 2001).

Conclusion

Discovery of new sources by the H.E.S.S. experiment leads to a better characterization of pulsar wind nebulae and exhibits new properties: an expanded, often asymmetric emission, an energy dependent morphology due to particles cooling. In many cases, leptonic model is prefered to hadronic model to explain observed spectra. PWNe multiwavelength analysis provide us information about evolution and physical properties of the surrounding media.

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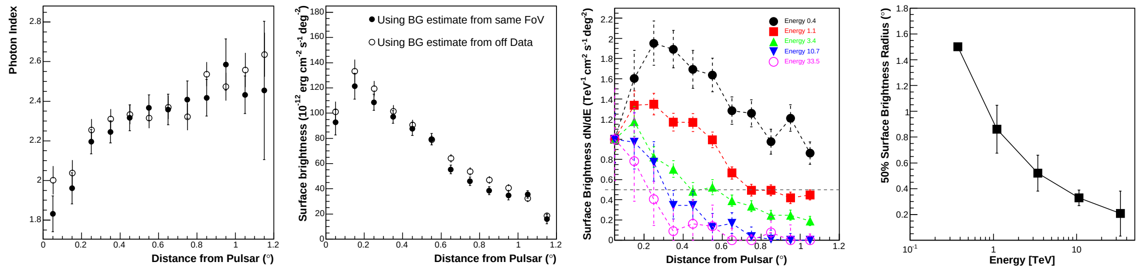

Fig. 4. Left: Spectral index and brightness dependence. The closed points are obtained by using a reflected background substraction. The opened points are derived using off-data (from Aharonian et al. 2006). Right: Relative surface brightness for energies between 0.2 TeV to 9 TeV (see also Funk 2007)

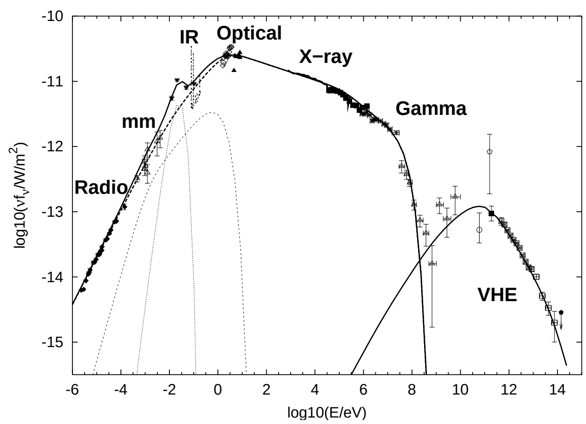

Fig. 5. Spectral energy density of Crab Nebula: spectrum fitted by a pure leptonic model (Horns & Aharonian 2004)

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