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Citation: [AIP Conf. Proc.](#) **1505**, 341 (2012); doi: 10.1063/1.4772267

View online: <http://dx.doi.org/10.1063/1.4772267>

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Unidentified VHE γ -ray sources and evolved pulsar wind nebulae - a possible connection?

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Abstract. Among Galactic VHE (very high energy, $E > 100$ GeV) γ -ray sources, pulsar wind nebulae (PWNe) form the most abundant class. At the same time, there are numerous sources of VHE γ -rays which are still unidentified. A firm identification of such objects requires a counterpart at other wavelengths. Middle-aged PWNe may account for many of these unidentified sources. While leptons that have been injected into a PWN a long time ago can still cause the observed VHE γ -ray flux, the present energy output of the pulsar is significantly reduced with respect to former times and powers only a faint synchrotron nebula which is difficult to detect with current X-ray observatories. We present a time-dependent model to study the spectral evolution of PWNe. With this model it is possible to roughly predict the X-ray emission of PWNe based on the VHE γ -ray observations only. These predictions allow to select those unidentified VHE γ -ray sources for which, assuming an evolved PWN scenario, a detection of an X-ray counterpart seems to be feasible.

Keywords: supernova remnants, gamma rays: theorie, radiation mechanism: non-thermal, individuals: (MSH 15-52, HESS J1825-137)

PACS: 98.38.Mz

INTRODUCTION

During the last decade, a new generation of Imaging Atmospheric Cherenkov Telescopes has discovered an increasing number of Galactic sources emitting VHE (very high energy, $E > 100$ GeV) γ -rays. Among these, pulsar wind nebulae (PWNe) form the most abundant class. Besides, unidentified sources are also very common in the VHE regime along the Galactic plane. A firm identification of these VHE γ -ray sources requires at least one unambiguous counterpart at other wavelengths. Middle-aged PWNe may power bright VHE nebulae without detectable emission in other wavebands. Therefore, these systems offer potential explanations for some unidentified sources. Current models of PWNe assume a relativistic, leptonic particle wind powered by a fast-rotating, energetic pulsar. The energetic plasma produces synchrotron and inverse Compton radiation, detectable across the whole electromagnetic spectrum. Since the energy output of a pulsar decreases with age, the supply of freshly injected, highly energetic leptons is reduced. Thus, the radiation from PWNe produced by older pulsars is dominated by accumulated, less energetic leptons which have undergone minor cooling compared to high energetic leptons. In particular, synchrotron emission in the X-ray regime is strongly affected by

FIGURE 1. *Left:* Typical evolution of the modeled spectral energy distribution of a PWN with time. The color scale represents the age of the PWN, starting with a young system (yellow) and proceeding in equidistant steps on a logarithmic time scale to an old system (dark red). *Right:* Spectral energy distribution (black broken line) of a generic middle-aged PWN decomposed into contributions by leptons from different injection epochs (solid colored lines). The grey areas represent the energy ranges covered by current X-ray and VHE γ -ray observatories.

the reduced energy output of the pulsar since X-ray emission requires very energetic leptons as well as strong magnetic fields. In the next section, we present a time-dependent model, which allows to investigate the spectral evolution of PWNe. Afterwards, the model is applied to already well-studied PWNe in order to probe its predictions regarding the X-ray emission. Hence, we can select suitable candidates of unidentified sources, where deep X-ray observations might reveal a multi-wavelength counterpart of the VHE γ -ray emission.

THE MODEL

In this section, we present the key ingredients of a time-dependent model for the spectral evolution of PWNe. For more details, the reader is referred to the forthcoming publication [1]. The injection of leptons into the pulsar wind is strongly dependent on the pulsar's energy output, more precisely on its rotational energy loss. The energy output of a pulsar evolves with time as

$$\dot{E}(t) = \dot{E}_0 \left(1 + \frac{t}{\tau_0} \right)^{-\frac{n+1}{n-1}},$$

where n is the braking index and τ_0 the initial spin-down timescale of the pulsar [2], [3]. We assume a conversion efficiency from energy output to relativistic leptons of 30%. The injected lepton distribution follows a power law in energy with index 2 between 100 GeV and 1000 TeV. Cooling effects and the time evolution of the magnetic field are adopted from the leptonic model presented by the authors of [4]. In addition, adiabatic energy losses are taken into account [5]. The radiation fields, required for inverse Compton radiation, are taken from the GALPROP code [6] for each source individually, while

FIGURE 2. SEDs for two sample sources, namely MSH 15-52 (left) and HESS J1825-137 (right). The black lines show the modeled SEDs resulting from a fit to the VHE γ -ray data. The violet bands depict the uncertainty of the model based on errors on the fit parameters and their correlations. The blue dotted bands denote the model prediction of the X-ray emission calculated for the published analysis regions. Red-filled circles represent VHE γ -ray data, while red-filled bands show the X-ray data. We also included γ -ray data (orange) from the Fermi-LAT. For better visualization we show higher-level error bands for the X-ray data and for the modeled SEDs. The data shown left are adopted from [9], [10] and [11] while data in the right panel are taken from [12], [13] and [14].

the radiation processes are calculated following [7]. The pulsar continuously injects electrons and positrons into the pulsar wind. Already injected particles suffer energy losses according to their energy, the current size of the PWN and its magnetic field strength. In case of a middle-aged PWN, the above-mentioned cooling effects lead to a steepening of the particle spectrum with many accumulated less energetic leptons inside the nebula. These leptons are able to power a bright inverse Compton nebula with a non-detectable X-ray counterpart. This phenomenon could explain a significant fraction of unidentified VHE γ -ray sources and has already been proposed [8]. To visualize this effect, we simulated the long-term evolution of a generic PWN system over a time span of 200 kyr (Fig. 1, left-hand panel). In addition we show the composition of a sample spectral energy distribution (SED) from a middle-aged PWN (Fig. 1, right-hand panel). The modeling shows that mainly the youngest, freshly-injected leptons account for the X-ray emission. At the same time, the injection history, meaning the accumulated leptons inside the PWN are observed in γ -rays.

MODEL APPLICATION

The model has two free parameters, namely the birth period of the pulsar and initial magnetic field inside the PWN. These parameters are determined with a χ^2 fit to the VHE γ -ray data using the MINUIT minimization package [15]. In Fig. 2, the results of the fits are shown for two individual PWNe. The HE γ -ray and VHE γ -ray data can be well described by the model, while the X-ray emission is strongly overestimated. However, this is expected since the spectrum extraction region in X-rays is significantly smaller than in the VHE regime. In order to reproduce the X-ray emission, this mismatch

has to be taken into account. We assume a constant lepton outflow velocity of $c/3$ in the innermost part of the PWN. Calculating the maximum age of particles located within a certain region and taking into account their specific cooling allows us to simulate the lepton distribution in the region used in the given X-ray analysis. For the calculation of the corresponding synchrotron SED we also consider projection effects from leptons in the outer PWN, located along the line of sight and contributing to the emission from the inner region. The resulting modified SEDs with their corresponding uncertainties, (also shown in Fig. 2), are clearly in better agreement with the observational data.

CONCLUSIONS

Our study indicates that, with the adaption of the spatial extent of the lepton population responsible for the observed X-ray emission, the presented time-dependent model allows to roughly predict the non-thermal X-ray emission of PWNe of different evolutionary states. Hence, transferring the model to yet unidentified VHE γ -ray sources which are considered candidates for middle-aged, evolved PWNe, the predictions of their approximate X-ray flux can help to evaluate whether deep X-ray observations with current satellites may be beneficial for a firm identification of the nature of such sources.

ACKNOWLEDGMENTS

The authors wish to acknowledge the helpful comments by members of the H.E.S.S. collaboration. Moreover, we thank Peter Eger for fruitful discussions concerning X-ray observations and their analysis.

REFERENCES

1. M. Mayer, J. Brucker, M. Holler, I. Jung, K. Valerius and C. Stegmann (in preparation)
2. F. Pacini and M. Salvati, *ApJ* **186**, 249–266 (1973).
3. B. M. Gaensler and P. O. Slane, *ARA&A* **44**, 17–47 (2006),
4. L. Zhang, S. B. Chen and J. Fang, *ApJ* **676**, 1210–1217 (2008).
5. O. C. de Jager and A. K. Harding, *ApJ* **396**, 161–172 (1992).
6. T. A. Porter and A. W. Strong, “A new estimate of the Galactic interstellar radiation field between 0.1 μ m and 1000 μ m,” in *International Cosmic Ray Conference, Pune, 2005*, vol. 4, p. 77,
7. G. R. Blumenthal and R. J. Gould, *Reviews of Modern Physics* **42**, 237–271 (1970).
8. O. C. de Jager and A. Djannati-Ataï, “Implications of HESS Observations of Pulsar Wind Nebulae” in *Astrophysics and Space Science Library*, edited by W. Becker, 2009, vol. 357, p. 451.
9. F. M. Schöck, I. Büsching, O. C. de Jager, P. Eger and M. J. Vorster, *A&A* **515**, A109 (2010)
10. A. A. Abdo et al., *ApJ* **714**, 927–936 (2010),
11. F. Aharonian et al., *A&A* **435**, L17–L20 (2005),
12. H. Uchiyama, H. Matsumoto, T. G. Tsuru, K. Koyama, and A. Bamba, *PASJ* **61**, 189 (2009)
13. M.-H. Grondin et al., *ApJ* **738**, 42 (2011),
14. F. Aharonian et al., *A&A* **460**, 365–374 (2006),
15. F. James and M. Roos, *Computer Physics Communications* **10**, 343–367 (1975).