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PeVatrons inside the Galaxy: Identification and acceleration mechanisms

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Abstract. Cosmic rays are charged particles that travel through space and reach Earth, including particles with multiple orders of magnitude of energy. To study them, one must consider the various interactions that occur with cosmic rays as they propagate through space. The so-called PeVatrons (PeV = 10^{15} eV) are possible sources of acceleration of these rays within the Galaxy up to energies of 10^{15} eV. In this work, we present the results of simulations of the gamma-ray spectrum of two PeVatrons detected in the central region of our Galaxy.

Resumo. Raios cósmicos são partículas carregadas que se propagam pelo espaço e chegam até a Terra, dentre eles temos partículas com várias ordens de grandeza energética. As fontes destas partículas ainda não foram identificadas, para estudá-las deve-se considerar as várias interações que ocorrem com os raios cósmicos durante sua propagação pelo espaço. Os chamados PeVatrons (PeV = 10^{15} eV) são possíveis fontes de aceleração de raios cósmicos Galáticos com energias de até 10^{15} eV. Neste trabalho apresentamos resultados de simulações de espectro de radiação gama de dois PeVatrons detectados na região central da nossa Galáxia.

Keywords. Astroparticle physics – Gamma rays: galaxies – Acceleration of particles

1. Introduction

Cosmic rays are charged particles that propagate in space and reach the Earth. They are detected by observatories such as the Pierre Auger, the Cherenkove Telescope Array (CTA), and the Large High Altitude Air Shower Observatory (LHAASO). These particles were discovered in 1912 by Victor Hess through an experiment that detected high-energy particles at an altitude of 5300 meters. In this experiment, it was observed that the ionization rate increases with altitude. Hess concluded that there is an external radiation that penetrates the Earth's atmosphere, for which he received the Nobel Prize in 1936 (Pacini 2017; Bandeira & Mackedanz 2019).

During the propagation of cosmic rays through the universe, particles interact with the medium and suffer collisions with other particles of background radiation and acceleration processes. When they interact with magnetic fields, the trajectories of cosmic rays are deflected, and when they arrive in the Earth's atmosphere, they interact with particles in the phenomenon known as an atmospheric shower (Anchordoqui et al. 2014). During certain interactions, cosmic rays lose energy. These losses make it possible to analyze some properties of these rays (Abeysekara 2017; Jóhannesson 2019). The cosmic rays that reach Earth with different energies can come from our Galaxy (Galactic) or outside (extragalactic).

Possible accelerators of cosmic rays in the Galaxy are PeVatrons, which accelerate particles to energies up to PeV (10^{15}). To identify the PeVatrons, the emission of gamma rays can be used. Pevatrons can generate gamma rays with energies between GeV (10^9 eV) and TeV (10^{12} eV) (Cristofari 2021). Progress in the study of PeVatrons can help to describe the knee region of the cosmic-ray spectrum (Jóhannesson 2019). At the center of our Galaxy, protons with an energy of 0.04 PeV have been detected by the H.E.E.S. Collaboration. In 2021, a population of PeVatrons detected by the LHAASO Observatory near the Galactic center (Cao et al 2021) was discovered. This detected 530 photons with energies between 100 TeV and 1.4 PeV from 12 ultrahigh-energy gamma-ray sources (Cao et al 2021).

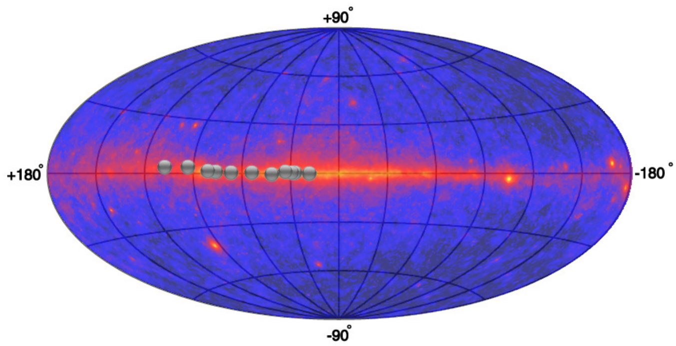

Figure 1. Skymap showing the location of the PeVatrons population.

2. Development and methodology

Examining the characteristics of the PeVatrons population in the region near the Galactic center, differences are found between individual PeVatrons. There are PeVatrons with possible sources from supernova remnants, pulsars, and stars (Malyshev, Cholis & Gelfand 2009; Roger 1988). The sources containing pulsars were selected for study in this work. Figure 1 shows a sky map that indicates the location of the PeVatron population.

For the simulations with these sources, the free software GALPROP was used, which solves the transport equation within the galaxy and allows the parameters to be adjusted in different properties (Strong 2007). To analyze the results, three types of

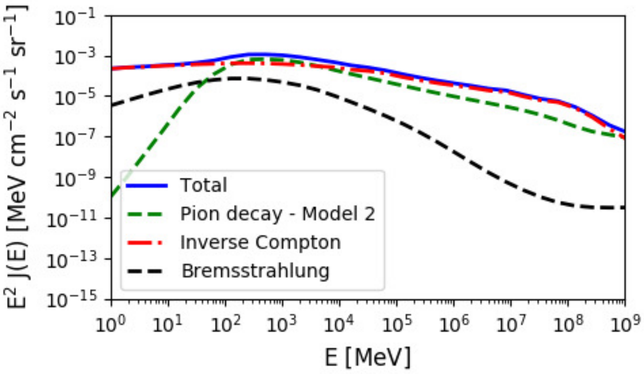

Figure 2. Gamma-ray spectrum LHAASO J1908+0621

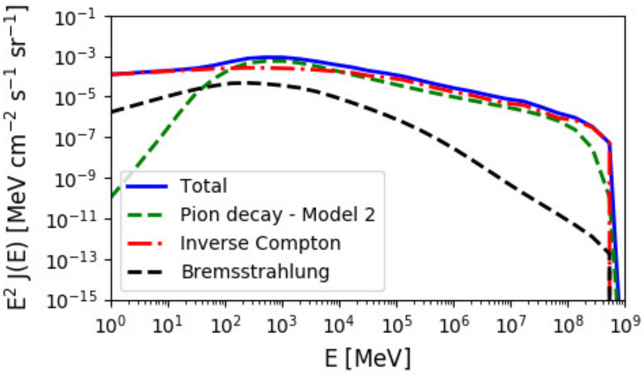

Figure 3. Gamma-ray spectrum LHAASO J1929+3651

gamma-ray energy loss and production were considered: the inverse Compton effect, where scattering occurs and the photon gains energy; the pion decay, which is fundamental for the identification of PeVatrons, and the bremsstrahlung effect, gamma-ray generated by the deceleration of charged particle. The results are displayed in the next section.

3. Results

Figures 2-3 show the gamma-ray spectra of LHAASO J1908+0621 and LHAASO J1929+3651. The largest contribution of gamma rays comes from the inverse Compton effect, and Bremsstrahlung is the smallest part of this total radiation. The pion decay is accompanied by a larger emission of gamma rays at higher energies.

4. Considerations

In this work, simulations of particles from the sources LHAASO J1908 + 0621 and LHAASO J1929 + 371 have been performed, showing the contributions of gamma rays with energies that characterize the existence of PeVatrons in the region near the center of the Galaxy. In the remainder of this study, the simulations will be compared with data measured by the observatories, and new simulations will be performed with different compositions and injection parameters at the source.

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