Observation and Mechanism Analysis of Pev-Scale Comic Ray

Yuanjing Li

The High School Attached to HNU-Meixihu High School, Changsha China

* Corresponding Author Email: liyuanjing@ldy.edu.rs

Abstract. As a matter of fact, the observation of high energy cosmic ray always plays a crucial role in astrophysics investigation, which can infer the processes happened in universe, e.g., the supernova burst, black hole merger. In recent years, PeV-scale gamma photons has been firstly observed by human beings, which marks a new step for cosmology study. With this in mind, this study will analyze the observation as well as mechanism for the generation of such extremely high energy gamma rays. To be specific, this study will first introduce the state-of-art observation tools for high energy particles. Subsequently, the advanced observation results will be demonstrated at the same time. Based on the results, the possible mechanisms will be presented in the meantime. Moreover, according to the analysis, the current defects and drawbacks of the observation as well as theorem will be discussed. Overall, these results shed light on guiding further exploration of high energy particles analysis.

Keywords: PeV-scale gamma ray; cosmology observation; ray mechanism.

1. Introduction

Recently, the China-Japan ASγ experiment in Tibet has observed the highest energy diffuse gamma ray radiation so far. The highest energy is 957TeV, which is close to 1PeV(1000 trillion electron volts) [1-3]. These ultra-high-energy gamma-rays are not directed toward known sources of low-energy gamma-rays, but rather diffuse across the galactic disk, the Milky Way's projection of the sky. This is the first time in the world to find evidence of the existence of the "PeVatron". The relevant observations will be officially published in PRL on April 5, which were reviewed by the APS as a milestone in the "mystery of the century" of the origin of high-energy cosmic rays.

The origination for the high-energy cosmic rays is remaining a mystery for a century, and has been listed as one of the 11 most cutting-edge scientific problems of the 21st century by the National Research Council of the United States.They mostly composed of leptons and heavy ions and other atomic nuclei. Cosmic rays typically below a few PeV energies are thought to be mainly produced within the Milky Way, and objects that can accelerate cosmic rays to PeV energies are also known as PeVatron. However, no Pevatrons have been observed so far. The main difficulty is that charged high-energy cosmic ray particles are deflated . The direction of its source cannot be traced by direct detection [4-6].

High-energy photons can be generated during their propagation. They are uncharged and travel in straight lines. The ASγ experiment found ultra-high-energy dispersing gamma rays on the silver disk, and its energy spectrum characteristics are consistent with the model prediction that the PeV energy cosmic rays and the Milky Way molecular cloud collide to produce gamma rays. It is like a string of "footprints" left by the PeVatron, which is an important evidence for the existence of the PeVatron in the Milky Way [7].

In 1912, Hess first discovered that the degree of air ionization significantly increased with increasing altitude. This observation successfully proved that the radiation that caused air ionization came from outer space. Later, Millikan referred to this extraterrestrial radiation as cosmic rays. Cosmic rays played a leading role in the early development of particle physics. Before the maturity of large-scale artificial accelerator technology, they were almost the only tool for studying cosmology. In 1932, Anderson discovered positrons (Nobel Prize in 1936); In 1936, Anderson and Neddermeyer discovered μ leptons; In 1947, Rochester and Butler discovered the K meson; In 1947, Lattes et al. discovered the π meson (1950 Nobel Prize; theoretical physicist Hideyoshi Tangawa won the 1949

Nobel Prize for proposing the meson theory of nuclear force); Chang discovered μ atoms in 1949; In 1950, Hopper and Bisbas discovered the Λ baryon.

The existence of vast downpours of air triggered by high-energy CRs was established by Kohlhörster, Auger, and their associates in the 1930s . Large detector arrays were put in place after the second world war to measure these extensive air showers. In 1958, at energy about 4 PeV, Kulikov and Khristiansen of Massachusetts Institute of Technology discovered in the MSU experiment data the area known as the cosmic ray knee joint, where the spectral index was hardened α~3.1. The Volcano Ranch was covered by a series of scintillation counters deployed by the MIT team in the following years [8].

This article preents analysis on the observation and acceleration mechanism of PeV photons, and explains some phenomenological significance.As a matter of fact, it is actually one of the core issues in the fields of high-energy space, high-energy sun, and high-energy astrophysics. It analyzes the observation methods of PeV scale ray, introduces the main results, and proposes some new prospects. The organization of this article is as follows. The first part introduces the research history and significance of cosmic rays, and elaborates on the milestones and main research results of CR. The second part introduces the definition and classification of CR for everyone. The PeV scale ray was highlighted in the third part, indicating its observation results and SNR ratio. The fourth part is about the acceleration mechanism of CR and the equations corresponding to the acceleration mechanism.

2. Basic Descriptions

Cosmic rays are a collective term for a stream of high-energy materials from cosmic space, the vast majority of which are protons (90% hydrogen nuclei) and contain a few alpha particles (9% helium nuclei), among other components. They travel through cosmic space at very high speeds and have extremely high energy and powerful penetrating ability. Cosmic rays are relativistic particles in interstellar space. They contribute to regulate interstellar chemistry and star formation, and are also an important medium for indirect observation of dark matter. Nevertheless, their origins have remained a mystery.

They can be roughly separated into two categories, primary cosmic rays and derived cosmic rays. The outside the solar system are collectively known as primary cosmic rays, and the secondary particle streams produced by the interaction are the derived cosmic rays. after the 1930's, various researches have gradually confirmed that primary cosmic rays have the following compositions: about 90% are protons， 9% are helium nuclei, 1% are electrons, and there are a small number of heavy nuclei, gamma photons, neutrinos and antiprotons.

According to the energy range and composition of cosmic rays, low-energy cosmic rays mainly refer to cosmic rays with energies in the range of 10^6 - 10^9 electron volts (eV). These cosmic rays are mainly composed of heavy ions, but also include a small fraction of electrons and heavy ions. The sources of low-energy cosmic rays are mainly the solar wind and supernova outbursts in the Milky Way. Medium-energy cosmic rays have energies in the range of 10^9 - 10^15 eV. The main components of these cosmic rays are protons and heavy ions, with a small fraction of electrons and photons. The sources of intermediate-energy cosmic rays are mainly high-energy particle gas pedals in the Milky Way, such as supernova remnants and interstellar magnetic fields. Supernova remnants are the debris left over from supernova explosions, which contain large amounts of energetic particles. These energetic particles are accelerated by the supernova remnant's magnetic field to form medium-energy cosmic rays. It accelerates and directs charged particles to form medium-energy cosmic rays. The main components of high energy category are protons and photons, with a small fraction of heavy ions and electrons. Scientists have proposed a variety of possible acceleration mechanisms, such as supernova outbursts, active galactic nuclei, and cosmic ray bubbles.

As a matter of fact, the origin and acceleration for them is actually an important issue in high-energy astrophysics, but the origin and acceleration of cosmic rays is still a puzzle to be solved. Currently, there are many possible sources of cosmic rays, including high-energy activity on the

surface of the Sun and other stars; supernova outbursts; supernova remnants; high-energy objects; the interstellar medium in the Milky Way; high-energy objects outside the Milky Way, such as quasars ; and the CBR. Currently, the possible acceleration sources include supernova outbursts, supernova remnants, the solar wind, active galactic nuclei, and interstellar collisions, with supernova outbursts and their remnants considered to be one of the most important acceleration mechanisms. Cosmic rays are the products of the evolutionary processes of various celestial bodies, especially the products of the evolutionary physical processes of various high-energy celestial bodies, and carry a wealth of information about these processes.

3. Observation of PeV-scale Ray

China's major scientific and technological infrastructure (Large High Altitude Air Shower Observator), consists of Kilometers Square Array, and Wide Angle Cherenko Telescope composition. To this end, we use the cheapest water as the detection medium, repeatedly optimize the design of the muon detector, conduct various scale experiments, and try to improve the sensitivity of the detector as much as possible to achieve the maximum detection area with the minimum cost [9]. The KM2A array (seen from Fig. 1) mainly uses electromagnetic particle detectors to measure the energy and direction of these positive and negative electron pairs to restore the primary photons, and when high-energy cosmic rays enter the universe, they will generate widespread atmospheric showers. It can accurately select ultra-high energy gamma ray events by the ratio of muons to positrons in a shower event With a large detection area of 1 km2 and the ability to accurately select them, it is also the most sensitive detector in the world today [9].

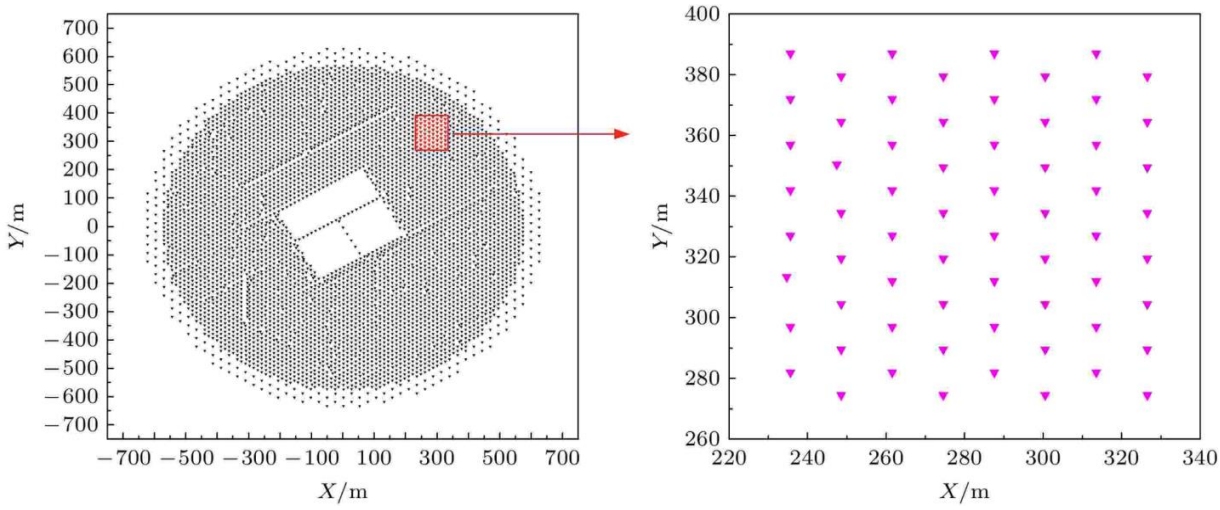


Fig. 1 A sketch of KM2A array.

It emits a pulsar wind composed in all directions, and the positive and negative electron pairs in the pulsar wind are further accelerated, generating multi band radiation, forming a pulsar wind cloud. As the detonation wave sweeps more and more material in the interstellar medium, its speed gradually decreases. It is generally believed that to accelerate the proton to PeV, the velocity of the detonation wave needs at least several thousand kilometers per second, The corresponding supernova remnants are only a few hundred years old, which proves that supernova remnants can indeed accelerate protons.

The highest energy photon detected by LHAASO comes from the star forming region in the constellation Cygnus (seen from Fig. 2), with an energy of up to 1.4 PeV, breaking the record for photon energy detected by humans from the universe [9].

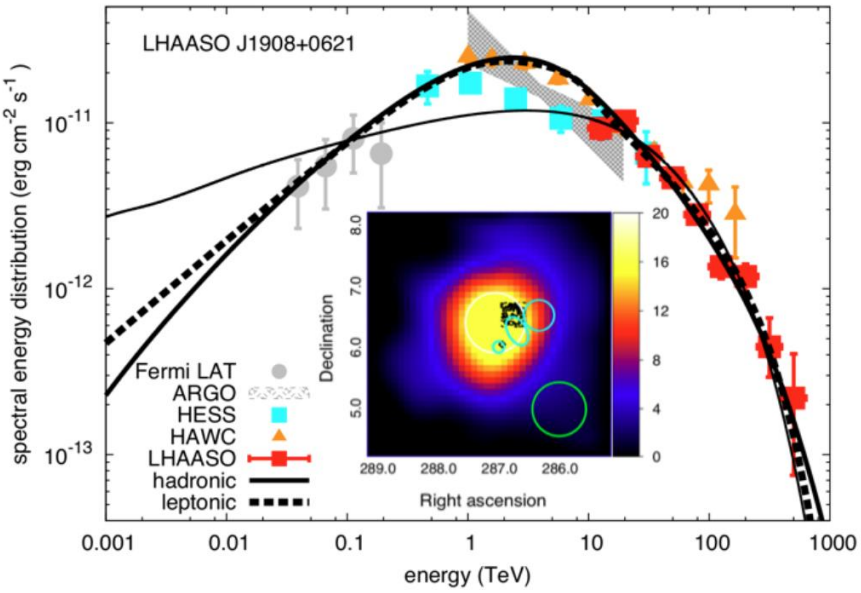


Fig. 2 LHAASO observation.

4. Acceleration Mechanism and Origination

The rate of energy (momentum) increase. It is one of the fundamental issues in the study of particle acceleration mechanisms Corresponding acceleration The time scale can be represented as:

$$T_{ac} \sim \frac{p}{qE} \sim \frac{cp}{qvB} \sim \frac{R_g}{V} \sim T_g(v/V) \tag{1}$$

The existence of a magnetic field in the Milky Way was discovered by Hiltner and Hall in 1949 due to the polarization of star light.In same year, Fermi proposed that the acceleration of cosmic rays may come from the interaction between charged particles and the moving "magnetic cloud" He pointed out that on average, each vertex collision between charged particles and a "magnetic cloud" can result in a particle gaining an energy increase proportional to its own energy, which is known as the Fermi acceleration mechanism. Imagine a procedure in which the test particles increase their energy proportionately to each 'encounter'. The large-scale shock waves of supernova remnants provide acceleration for diffusion shock waves.

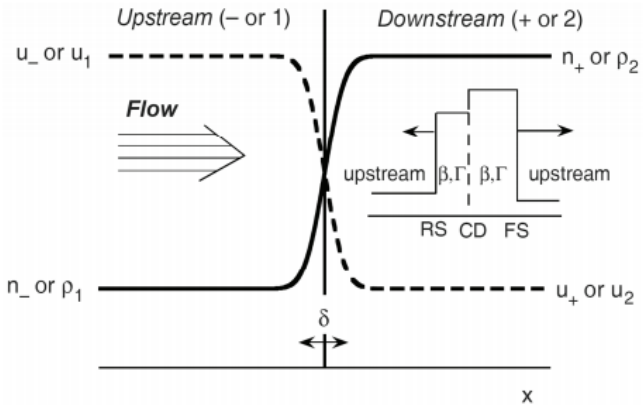


Fig. 3 A sketch of the shock wave acceleration.

The diffusion shock wave acceleration mechanism refers to the process in which the shock wave generated during a supernova explosion interacts with the surrounding medium, causing charged particles to be accelerated multiple times by a plane shock wave, thereby accelerating low-energy particles to a high-energy state (seen from Fig. 3). After explosion, the shock waves generated by the explosion push the surrounding gas and dust towards the periphery, forming supernova remnants.

When the shock wave interacts with the surrounding medium, a diffusion shock wave is formed, which is the main site for the acceleration of high-energy particles. There are many possible scenarios for these scattering. As a matter of fact, diffusion shock wave acceleration is considered one of the most effective mechanisms for accelerating high-energy celestial particles, and the large-scale shock waves of supernova remnants provide a platform for this mechanism [10-14].

5. Limitions and Prospects

At present, important progress has been made in the observation of Pev cosmic rays, but there are still limitations in the study of their generation and mechanism. First of all, due to the very high energy of Pev gamma photons, their propagation process in the universe will be affected by the cosmic microwave background radiation and other factors, which brings certain difficulties to the observation and research. Moreover, the sensitivity of the existing detectors for Pev gamma photons is not high enough. Therefore, it is difficult to detect enough Pev gamma photons, and the event of observing Pev gamma photons is very rare. Secondly, the generation mechanism of Pev gamma photons is not yet completely clear, and scientists have great controversy about their acceleration mechanism and source. Since the proportion of Pev gamma photons in cosmic rays is very low, it is still difficult to study their source and the mechanism of their generation and acceleration. Therefore, in order to deeply study the production and mechanism of Pev gamma photons, first of all, the observation means and technology need to be further improved. More observation experiments should be carried out to improve the sensitivity of observation and the accuracy of spectral measurements in order to provide more detailed observation data and accurate spectral measurements. The energy resolution and angular resolution of the detectors should also be improved to minimize the influence of background interference on the observation results. Secondly, the generation of them should be further studied. A more accurate and better theoretical model should be established to explain the observed phenomena, and the existing theoretical model should be verified and corrected by combining experimental and observational results. In addition, laboratory simulations should be carried out to study the interaction and acceleration process for Pev gamma photons should be studied in depth. These studies will help to reveal the origin. It is hoped that in the future, greater breakthroughs and progress will be made in the observation and study of high-energy cosmic rays. We will be able to gain a deeper understanding and make greater contributions to the development of cosmic physics.

The Xizang ASγ experiment released another important related result, which for the first time revealed the presence of gamma rays in the direction of SNR G106.3+2.7 in the supernova remnant, exceeding 100TeV (100 trillion electron volts). The energy (greater than 100TeV) and spatial distribution of these gamma rays indicate that SNR G106.3+2.7 is the most likely PeVatron candidate found in the Milky Way so far. Taken together, these two important results from the ASγ experiment, respectively from the PeVatron candidate objects and the spatial distribution, indicate the existence of the PeV cosmic ray accelerator in the Milky Way, which is an important step towards solving the mechanism issues [13].

The Tibet ASγ experiment is located in Yangbajing Town, Tibet, at an altitude of 4300 meters. In 2014, the ASγ experiment team added an innovative underground Muon water Cherenkov detection array with an effective area of 3,400 square meters to the existing 65,000-square meter cosmic ray surface array, which is used to detect muons generated by the interaction between cosmic ray protons and the Earth's atmosphere. In this work, the ASγ experimental group used data from both surface and underground detector arrays to reduce the cosmic ray background noise above 100TeV to one part per million, thus greatly improving the sensitivity of gamma ray detection. This is the key technical basis for a series of important discoveries in ASγ experiments in recent years [14].

6. Conclusion

This study analyzes the main research results of cosmic rays in recent years and the basic information on the classification of cosmic rays. It focuses on the observation method of Pev cosmic rays and the recent observation results. It also summarizes the acceleration mechanism proposed in recent years. The study of cosmic rays is very important for human beings to understand the origin and evolution of the universe. They can not only tell us the distribution of high-energy objects and materials in the universe, but also help us to understand the cosmology. Although there are still limitations in the current understanding of the generation of PeV photons, it is believed that the mechanism can be revealed through further observational experiments and theoretical studies.

Author Contribution

All the authors contributed equally, and their names were listed in alphabetical order.

References

[1] Zhuang Y. Application and prospect of data on charged particles and medium high energy nuclei. Nuclear Physics Review, 1992, 4.

[2] Wang X, Xue R. Research on multiple messengers of high energy neutrinos and cosmic rays. Knowledge of Modern Physics, 2019, 2: 23-27.

[3] Liu J, Cao Z. Chinese Journal of Physics, 2021, 50(6): 393-394.

[4] Xu R. Black holes act as accelerators for extremely high-energy particles. Physics, 2019, 48(3): 187-187.

[5] Peng Q. Celestial Origin of extremely ultra-high Energy Cosmic Rays: A Model of Active Galactic Nuclei with Magnetic monopoles. High Energy Physics and Nuclear Physics, 2002, 11: 104-111.

[6] Bi X. Observation of high energy cosmic ray. Science and Technology Review, 2006, 24(0609): 8-12.

[7] Peng X, Yuan Q. Advances in direct detection of cosmic rays. Advances in Astronomy, 2019, 37(1): 16-26.

[8] Kachelriess M, Semikoz D V. Cosmic ray models. Progress in Particle and Nuclear Physics, 2019, 109: 103710.

[9] Liu R. High Altitude Cosmic Ray Observatory and Ultra-high Energy Gamma Ray source. Acta Astronomica Sinica, 2021, 62(4).

[10] Liu S. Acceleration of high-energy Charged particles in the Universe. Science in China: Physics, Mechanics and Astronomy, 2015.

[11] Cao L. Discovery of Ultra-high energy cosmic rays. Science World, 2021.

[12] Abduelkreem N A R. Generation of light (anti) nuclei and hypernuclei in high-energy proton-proton collisions. China University of Geosciences, 2021.

[13] Ruan J. The Magic of Cosmic Rays [J]. Physics Teaching, 2022.

[14] Luo X J, Wang Q X, Tian H, et al. Research and development of cosmic ray Muon imaging system based on plastic scintillator. Progress Report on Nuclear Science and technology in China, 2021.