

High Energy Cosmic Generation Form Collisionless Shock Wave Acceleration

Kaiyi Chen*

Beijing Royal school, Beijing, China

* Corresponding Author Email: chenkaiyi@st.brs.edu.cn

Abstract. The collision less shock wave one of the shock waves that is more likely to detect in the plasma that come from the magnetosphere, interplanetary space and so far. The most significance difference between other shock wave is the direct collision between particle is almost not exist. To be specific, the bow shock wave that occur by the interact of magnetosphere of an astrophysical object and solar wind is one of the collisions less shock wave. The collision-less shock wave in the universe could accelerate the particle in to high energy and form cosmic rays. In this essay, the basic reorganization of collision-less shock wave will be illustrated. On this basis, this paper is going to analysis a few mechanism of how the collision-less shock wave accelerate the particle and the recent experiment about the shock wave. According to the analysis, lots of state-of-art observations can be explained. These results shed light on guiding further exploration of high energy cosmic ray.

Keywords: Collisionless Shock Wave Acceleration; high energy particles; cosmic ray.

1. Introduction

Cosmic ray is the charged high-energy subatomic particles that comes from the outer space. Generally speaking, the composition of cosmic ray that human discovery until now common included pure protons, alpha particle (He-4), heavy element etc. [1]. The source of the cosmic ray is the problems about the way of spreading the cosmic ray. Finding the source of cosmic ray cannot spited from the spreading of it because new cosmic ray will produce while spreading. Until now, an opinion than been widely accepted about the origin of cosmic ray is that cosmic ray is the by-product of the celestial evolution such as the blast of supernova remnants [2].

As a key of the exploration of the universe, since Victor Franz Hess, a physicist who came from Austria, discover it, The researching of the cosmic way contributes a lot to human civilization. In particle physics a physicist who from California Institute of Technology called Carl David Anderson proof the existence of positive electron through observed the orbit of cosmic ray in the cloud chamber in 1932, This discovery directly lead to the acquirer of Nobel Prize in Physics in 1936 for him. After that, C.D Anderson discovery a new particle called Muon through further researching of cosmic rays. Besides, the researching of cosmic ray will not only distribute to particle physics, but also in aerospace engineering. Since the fatal cosmic rays out side the Earth atmosphere and magnetosphere. To protect the astronaut and the interior of space craft researching on cosmic ray is going to effect the designing of the space suit and space craft. Apart from that, cosmic ray researching also work as an significant part in other area such as by the studying of cosmic ray and the planet magnetosphere, one could speculate does the planetary biosphere suit for human to live or not [3-6].

Turning in to the collision-less shock wave acceleration, it is a kind of shock wave that occurs on a length scale much smaller than a particle collisional mean free path. It is mainly occured in the magnetized plasma generated by the supernova oxygen explosion process. Since its a astronomical phenomenon, observation of it is important. By using dual-beam interferometer and indicate the number of interference fringes of the plasma, one can observe the collision-less shock wave through the density of electron and index of refraction of plasma that come from this formula. This method is called interference method, it could clearly record the producing of shock wave and significant parameter [7]:

$$\Delta\phi = \int (k_{plasma} - k_0)dl = \int (N - 1)\omega/c dl \quad (1)$$

Here, k_0 is equal to ω/c which represent the value of wave in vacuum, 'N' is the Refractive index of plasma.

In previous researching, human reveal these characteristics of collision-less shock wave acceleration. For instance, various mechanism of acceleration is one of them and the most efficient acceleration mechanism is diffusive shock acceleration. However, the particle needs enough big initial speeds before shock diffusion acceleration take effect which means there must be some pre-acceleration. Thus, the most possible acceleration would be shock surfing and shock drifting acceleration. During the acceleration process, ion with smaller muzzle velocity more depends on shock surfing to accelerate. On the contrary, ion with bigger muzzle velocity more depends on shock drifting [8]. On the other hand, because passive observation contain massive of instability. Thus, produce a collision-less shock wave in artificial way is going to be a strong support of the researching. In the multiple way of producing collision-less shock wave, this study is going to introduce the one that use strong laser to driven. The principle of it is high-density plasma expands to low-density plasma, driving collision-free electrostatic shock waves in low-density plasma. In this researching, our antecessor find out that The collision-free electrostatic shock wave velocity is proportional to the logarithm of the initial plasma electron thermal velocity and the initial plasma electron density ratio, and the collision-free electrostatic shock wave only exists within a certain initial density ratio range [9]. Another researching focus on the collision-less shock wave in the laser-driven plasma flows. The researcher use technology to produce collision-less shock wave way to solve serval problem. Subsequently, they use their result explain the Anomalous neutron yield that was observed in the Neutron experiment that Shen-Guang III Giant High Peak Power Laser Facility driven out [10].

In this essay, section after introduction is the description of the cosmic rays. In this part, this study is going to illustrate the classification of cosmic rays and different high energy particle. On the other hands, this study is going to describe the principle of the detection of cosmic ray and what do human detect until now. In the next part is the description of collision-less shock wave acceleration by using some formula and picture that human discover. Section goes next is experiment observation, the stimulation and experiment result come from PIC (particle-in-cell stimulation) is going to be here. Last part is limitation and future outlooks, and Conclusion in this part, which will describe what kind of limitation of the current state-of-art results. Afterwards, this research will expound the future of the collision-less shock way in my own opinion.

2. Description of Cosmic Ray

According to the different standard, cosmic rays can be classified in to different types through different judgments. It could be divided in to primary cosmic rays and secondary cosmic rays through the origin of the cosmic ray. Primary cosmic rays mean that it is a kind of cosmic rays that directly comes from the source of radiation such as black hole, supernova explosion. Secondary cosmic ray is a concept that relative to primary cosmic ray, the origin of secondary cosmic ray is primary cosmic rays. They come from the strike of primary cosmic ray with other object such as the atmosphere of a planet or another cosmic ray. According the the description above one can easily find out that secondary cosmic ray can produce another secondary cosmic ray. During this process the energy inside the cosmic ray is attenuate until it disappear through the collision with other object.

On the other hands, cosmic ray could also classified by the composition that they formed. Under this standard, one has helium nuclear flow which is represented by α rays, electron flow represented by β rays and electromagnetic waves represented by γ rays. Apart from that, cosmic ray also contain neutrino flow in it. On the other hand, cosmic ray also can spited in to charged and uncharged or neutral. For instance, α rays is charged flow and γ rays is uncharged.

As mentioned above, cosmic ray is form by various particle flow, same to cosmic rays, high energy particle also can sort in to different types. The definition of high energy is "Particles above tens of gigaelectron volts". So far, human discover dozens of particle that suits seriously to the definition of high energy particle. In this particle, mesotron, photon and hyperon are the most common type. Beside,

neutrino or lepton is also high energy particle but not well known. Additional, it is worth mentioning that low energy particle can accelerated to high energy. However, human can only accelerate proton and electron to high energy, other high energy particle can only form from the reaction between the collision of particle.

The method of the detection of the cosmic ray can be simple divide in to direct detection and indirect detection. However, it is worth to mention that no matter direct or indirect detection, the principle of detection is observing the light that comes from Cherenkov effect. The difference of the is the way of receiving the rays and the range that it suit for.

Direct detection is an original detection way and only suit for particle under 1014eV. It use a particle detector carry by high altitude balloon or artificial satellite rising above the atmosphere to detect cosmic ray. The scientist, called Victor Hess, who first detected the cosmic ray achieved by using a particle detector carried by high altitude balloon in 1912 [4].

Indirect detection in suit for particle higher than 1014eV because of the low flux that these particles are. On the other hands, indirection detection avoids a fatal problem that direct detection has which is the effect comes from the solar wind [11]. As a high energy particle flow, solar wind can easily affect the data of particle detector carry by high altitude balloon or artificial satellite. Since indirection detection would not. It track the fluorescence light that produced by interaction between primordial cosmic rays and the atmosphere and analyses it to infer the properties of primordial cosmic rays. In 21century this method using an array that form by multiple detectors associate with the fluorescence detectors, a kind of detector that could capture the fluorescence light, had found particle beyond 1020eV.

Nowadays, advanced technology has participated in the detection of the cosmic ray. In the beginning of 21 century, a group of scientists propose a new way of observing the cosmic ray which called "Wide Angle lens" [12]. They use this to replace the traditional reflector lens to observed because wide angle lens have wider field of vision than reflector. On the other hands, reflector need serval array that form by multiple optical system to provide a large field coverage. However, the cost in space observation is rising geometrically by the increasing volume of observation device. Thus, this kind of observation system is going to be more and more unsuitable through the rising demand of space observation.

3. Principle of Collisionless Shock Wave Acceleration

Modern observation identify that the shock wave could accelerate the particle. In solar system, the most frequently shock wave one observed is interplanetary shock, which is the interaction of different field of solar wind. Based on this fact, one could speculate that shock wave acceleration is one of the main accelerated patterns to particle. There are multiple mechanisms about the collision-less shock wave acceleration. The two of the main mechanism that modern science research manifest are first-order Fermi acceleration and shock drift acceleration. On the other hands, these mechanism have their suiting accelerated object. For instance, shock drift acceleration are mainly suit for the acceleration of electron in a perpendicular shock wave. In the following text, this study is going to introduce few more acceleration mechanism which our senior discover. Each of these mechanisms have their unique features, but their common feature is the particle is accelerated under the rebound action between shock wave and other object and gain energy to high energy range and commonly accelerated by electric field.

Primarily, this study illustrates the first-order Fermi acceleration. Before describing, It is worth to mention that there are two model in Fermi acceleration, one is what this study is going to introduce, other one is second-order fermi acceleration which also called stochastic acceleration which is an acceleration mechanism more depends on magnetized plasma rather than collision-less shock wave. On the other hands, it is wort to mention that the preconditions of these Fermi acceleration are collision-less surrounding. The reason of it is frequent collisions will cause severe energy loss, so no acceleration will be generated and particle won't reach the energy requirement of Fermi acceleration.

First-order Fermi acceleration describes a possible way that particle accelerate in the high energy in cosmic ray. The energy that particle gain from in first-order Fermi acceleration is describe as “Magnetohydrodynamic turbulence that cause by the relative motion of the upstream and downstream in shock wave lead to the throw angle scattering motion of particle to rebound between the upstream and downstream to gain energy” [13]. During this process, the particle is accelerated by the relative motion of the scattering center.

The principle of shock drift acceleration is “The velocity vector of the fluid V inside the shock wave is not always on the same direction of the magnetic field. Through the Faraday law of electromagnetic induction, $\mathbf{E} = -\mathbf{V} \times \mathbf{B}$, a vortex electric field will be produced. Thus, the particle will drift along the electric field depends on the force by magnetic and electric field” [14].

The reason why this mechanism is more suit for electron in is the perpendicular shock wave is electron have higher speed and smaller cyclotron radius than ion which easier to be accelerated through shock drifting acceleration and reduce the possibility of the resonance with the shock wave. Other hands, shock drift acceleration is more likely to be gained energy through perpendicular shock through the high gradient difference.

The following mechanism is shock diffusion acceleration. It is the head-on in interaction between the particle and the shock wave. The principle of it is the particle scattering inside the shove wave and repeatedly come in and go out the shock wave. During this process, the elasticity of the magnetic field, there is no lose or infinitesimal low energy lose. Which become a precondition of the energy rising insides the particle [15]. Under the situation that has been illustrated above, the diffusion of particle can be describe in the following formula

$$\frac{\partial f}{\partial t} + \mathbf{U} \cdot \nabla \mathbf{f} = \nabla(\kappa \nabla f) \quad (2)$$

Here, K is the diffusion tensor; U is the velocity of the plasma in the background [13]. For shock diffusion acceleration, particle that has higher cyclotron radius are more likely to strike the wave front and make shock diffusion acceleration happen.

4. Stimulation & Experiment Observation

This part is divided into two sub-parts: data come stimulation that former researching and observation result to the collision-less shock wave. This study will illustrate the predecessor’s researching achievement and settle them into a table to get an intuitionistic exhibition. As the article mentioned above, solar wind is the most frequent shock wave in solar system. It leads to the generation of the cosmic ray in the solar system. This cosmic ray is observed by human and recognized that it contains 99% of protons and 1% of electrons. Further studying indicate that the heavy elements such as lithium contain have higher relative abundance than that on earth. Base on a strong interaction model, the average nucleon number is extrapolated. Therefore, Fig. 1 shown above predicts the trend of heavy element content in universe with the energy increasing is provideed [2]. It reveals the non-pervasive of the distribution of the element in the universe

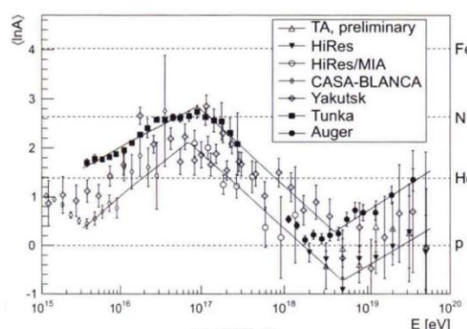


Fig. 1 The origin of cosmic High-energy particles

In the researching of the collision-less shock wave, the mankind had proceeded massive of numerical studies and summarize the experience through the searching. The most important thing that is worth to mention is that the three-dimensional stimulation (1-,2- and 3-dimensional) indicate that 1-and 2-stimulation is less reliable than 3-dimensional stimulation since the 3- dimensional modes, is more approach to actual situation and it is significant for the generation of the shock wave. Therefore, in the following data, 1- and 2- will be less likely to shown to leave more blank for more useful data.

PIC simulation describes the motion of electronic particle in a magnetic field to illustrate the collision-less shock wave. The basic train of the PIC is calculating the distribution of density of charge and current through the initial location and velocity of the particle. Then get the distribution of magnetic field by Maxwell function. Subsequently, the magnitude of Lorentz force is been pulled out. Therefore, through the Lorentz force that particle receives, one could predict the velocity and position that the particle belongs in the next moment. The results presented in Fig. 2 and Fig. 3 are the PIC stimulations using the observation that come from the ACE shock wave list [13], which represent an event that occur in 1998. The researchers use PICs concluded the characteristics of shock wave parameter that is beneficial to particle acceleration.

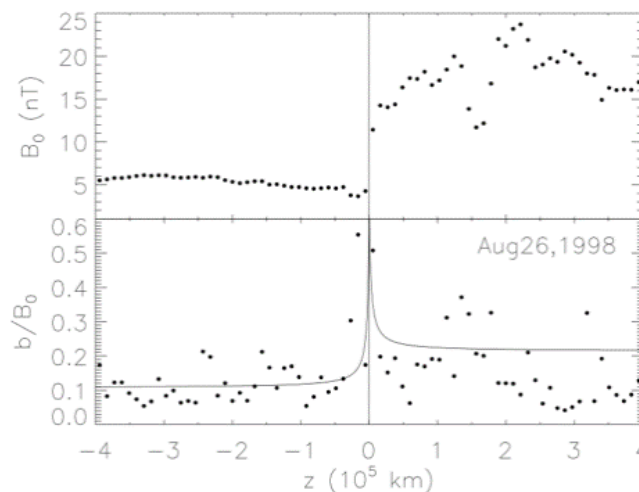


Fig. 2 Simulation Study of Particle Accerleration Mechanism at Interplanetary Shock. B_0 is the total magnetic field, b is the disturbance magnetic field, z is the distance to the shock wave.

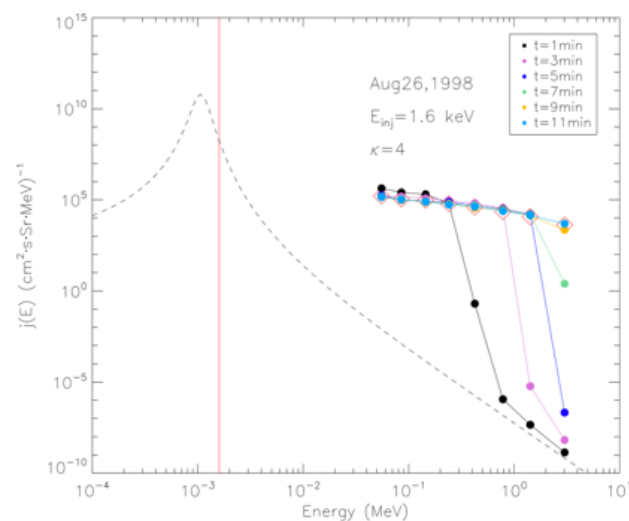


Fig. 3 Simulation Study of Particle Accerleration Mechanism at Interplanetary Shock. The energy spectrum changes by time in the stimulation, red square represents the average data in 5min. Red line is the energy inject.

5. Limitations & Prospects

The limitation of this text is mainly come from the category of this article. The character that is limited by the former researching destined that it cannot include excessive of innovation. Apart from that, since most of the information are collected from former researcher, their loophole in the article might be inherit. Secondly, the limitation said above which is the loophole of former research will be inherit could be make up through a similar experiment that the review author done. Nevertheless, due to the lack of necessary device and knowledge of using the device, one cannot proof the result or identify the mistakes they have. However, the article introduced can satisfy the demand of essay and the technique of former researcher use are reliable enough. This means even the error exist, which is still in the acceptable range. The last limitation is the limitation of the information acceptance. Since the foreign academic websites is difficult to find our because of a few technical issues it is hard for me to find article that comes from foreign researchers. This means that this study has been limit in to a changeless field. This directly cause a monotonous reference source of my article is and ignoring most of the opinion from the worldwide. Thus, one cannot get an all-round and objective view for my topic. Fortunately, the foreign opinion is been conclude in the references that this study introduced because other scholars introduce massive of data that come from the global. In this aspect, this disadvantage could be made up a few.

For futures works, it is necessary to provide effective solution for these limitations. On this basis, this study will provide the following solution and ideas for improvement. First of all, since review is a kind of writing for which one cannot repudiate itself. Therefore, to make the research more innovative, one should break away as one could from the limitation of a summary of previous literature. In this way, by adding the opinion that process from my own thinking, the innovation of the article will improve and the loophole might not inherit. These measures above would lead to objective an innovative article finally. On the other hands, to make sure not inherit of the loophole my future working is to participate in a qualified institution to obtain essential support.

6. Conclusion

In summary, this paper generally discusses the high energy cosmic that generated by collision-less shock wave from particle physics. Specifically, this study introduces the form of different cosmic rays and their characteristics. Moreover, according to the of the principle of the acceleration collision less shock wave, the theory of the acceleration has been revealed primarily. In addition, the essay reference a few stimulations experience to discuss the ancestor researching result. Besides, limited by the fundamental facilities, the article cannot give out a result that come forms owns experiment. In the future, the improvement of necessary device is going to make the article more objective, Overall, these result offer guideline for primary studier on this field and illustrate a few of the practical significance of corresponding research.

References

- [1] Yang R Z. LHAASO and the origin of cosmic rays (in Chinese). *Sci Sin-Phys Mech Astron*, 2022, 52: 229501.
- [2] Zhang Y. The origin of cosmic High-energy particles. University of Science and Technology of China, 2021.
- [3] Atri D, Hariharan B, Griebmeier J M. Galactic Cosmic Ray–Induced Radiation Dose on Terrestrial Exoplanets. *Astrobiology*, 2013, 13(10): 910–919.
- [4] Anchordoqui L, Paul T, Reucroft S, Swain J. Ultrahigh Energy Cosmic Rays: The state of the art before the Auger Observatory. *International Journal of Modern Physics A*. 2003, 18 (13): 2229.
- [5] Moskalenko I V, Strong A W, Ormes J F, Potgieter M S. Secondary antiprotons and propagation of cosmic rays in the Galaxy and heliosphere. *Astrophys. J*. 2002, 565: 280-296.

- [6] Xiang Y M, Jiang Z J, Zhang L. Research on the astrophysical origin of high-energy particles in the universe. *Journal of Yunnan University (Natural Science Edition)*, 2014, 36.S2: 117-125.
- [7] Liu X. The research on detect technology for Space collisionless Shockwaves. *Proceedings of the 26th National Symposium on Space Exploration of the Space Exploration Professional Committee of the Chinese Space Science Society. Ed.,* 2013, 462-470.
- [8] Yang Z W, Lu Q M, Guo J, et al. Mechanism of ion acceleration at perpendicular collision less shocks. *Chinese J. Geophys (In Chinese)*, 2008, 51(4): 953~959.
- [9] Jing L J. Research on collision-less shock waves driven by strong lasers. *China Academy of Engineering Physics. PhD dissertation*, 2017.
- [10] Zhang W S. Collisionless Shock Waves and Ion Acceleration in Laser-Driven Plasma Flows. *Diss. China Academy of Engineering Physics*, 2018.
- [11] Gao Q. Exploration and application of wide-angle lens in cosmic ray detection. *Technology Innovation and Application*. 2002, 12.09: 193-196.
- [12] Lamb D J, Chipman R A, Hillman L W, et al. Wide-angle refractive optics for astrophysics applications. *AIP Conference Proceedings. American Institute of Physics*, 1998, 433(1): 428-433.
- [13] Kong F. Numerical Simulation Study of Particle Acceleration Mechanism at Interplanetary Shock, *University of Chinese Academy of Sciences (National Space Science Center, Chinese Academy of Sciences)*, PhD dissertation, 2018.
- [14] Chen X, Du C. Theory of Shock Diffusion Particle Acceleration. *China Science and technology information*. 2020, 05: 96-97.
- [15] Shen J. Discuss of the shock diffusion acceleration in the solar radio burst. *Southeast University, Master degree thesis*, 2007.