Acceleration of Ultra High Energy Cosmic Rays (UHECR) due to Preon Star Unipolar Induction

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Abstract

How do cosmic rays attain their incredibly energies, up to 10^{20} eV? This is one of the great astrophysical mysteries of our time. Neutron stars in the form of pulsars and magnetars are thought to be possible acceleration sites for these particles but no known acceleration mechanism can still account for the highest energy levels. The aim of this study is to give a short review of the state of cosmic ray research, propose varioust constraints to the cosmic rays and their acceleration and then with respect to these constraints suggest an alternate mechanism based on unipolar induction within preon stars. Preon stars are theoretical objects with properties similar to neutron stars and would therefore be a good candidate for cosmic ray acceleration.

1 Introduction

This report will give a short review on the subject of cosmic rays and discuss various constraints on the acceleration of CR. The aim of this report is to, with respect to these constraints, propose an alternative mechanism of acceleration for UHECR based on unipolar induction in preon stars using the theoretical models introduced by Johan Hansson. [1] [2] The paper will restrict itself to UHECR and will therefore only deal with CR $> 10^{19}$ eV.

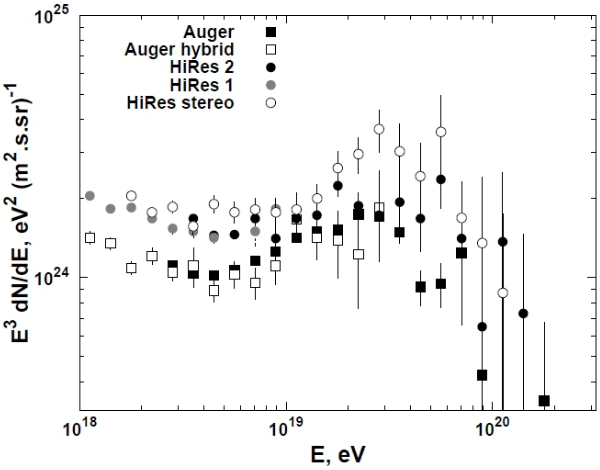
2 Overview

Ever since its discovery in the 20th century the origin of UHECR has been a great mystery. Not only do they have extremely high energies but because of the GZK feature UHECR can not possess energies greater than 10^{19} eV if not the distance from the UHECR source to Earth is less than 5 Mpc; a relatively short distance astronomically speaking. The arrival directions of UHECR also seem to be more isotropic than it should. [3] [4] [5] Many questions and few answers indicate that our current knowledge of the Universe is insufficient, opening up the opportunity for new, exotic physics to be applied. One of these theoretical models is the preon model, a continuation of the standard model which introduces a fermion called the preon.[6] Assuming preons exist there could exist a new type of star called the preon star with a radius much smaller than a neutron star's but with a similar magnetic field, giving us interesting new possibilites for acceleration sites. [2]

2.1 Observational data

The study of CR has always been primarily experimental. When UHECR enters the Earth's atmosphere and strikes a molecule it produces a number of subatomic particles called cosmic ray showers or air showers. It is possible by analyzing these showers to discover many of the traits of the original CR. This report will look at results from two observatories namely the High Resolution Fly Eye's (HiRes) detector and the Southern Pierre Auger observatory (PAO).

2.1.1 Energy Spectrum



Figur 1: The UHECR spectrum measured by HiRes and Auger.

The energy spectrum generally follows a broken power law $\propto E^{-2.7}$ with a steeper flux at energies greater than the GZK feature (description below) as predicted. The spectra given by HiRes and Auger are consistent with respect to the systematic error estimated to an order of 20%. Thereupon both HiRes and Auger seem to agree about the energy flux for CR. [3] [7]

2.1.2 GZK Feature

1966 Greisen, Zatsepin and Kuzmin [8] pointed out that the cosmic microwave background radiation (CMB) should affect and constrict the maximum energy of UHECR. If a proton has energy $\propto 10^{20}$ the CMB becomes opaque. Due to the Doppler effect the photons of CMB will be relatively blue shifted and then interact with the proton creating pions through the photopion production.

$$\gamma + p \to p + \pi^0 \tag{1}$$

The cross section for reaction 1 is, with the threshold energy of 10^{20} eV, $\sigma = 2 * 10^{-28} cm^2$ and the photon density is $\rho = 400\ cm^{-3}$, giving a mean free path for the particle $\lambda = \frac{1}{\sigma * \rho} \simeq 10^{25}$ cm or ~ 5 Mpc. This means that a proton of energy $> 10^{20}$ eV will lose energy to a level below this threshold if it travels farther than 5 Mpc. [9] [3]

2.1.3 Composition

The composition of CR is naturally crucial information to advance in UHECR research. The bulk of CR appears to consist of protons with a small percentage of heavier nuclei. However, at the moment no observatory has a definite answer to the primary composition of CR in the higher energies. While HiRes seem to agree with the proton composition even in the higher energy levels the experiments conducted at Auger observatory indicate a gradual change towards heavier nuclei as the energy increases. Geographically, since HiRes is placed on the Northern hemisphere and PAO on the Southern, one might argue that the differences can be explained due to the presence of nearby sources. The composition would therefore vary by the location of where the observation is carried out. PAO has analyzed and compared events arriving from the Northern respectively Southern celestial hemisphere, though, and no systematic difference could be detected. It should be noted that a similar comparison is yet to be exercised at HiRes.

Another explanation could be the varying event sample selection method used at HiRes and PAO. The reason is that none of the detectors at HiRes observe the whole sky but only up to a 31° elevation from the horizon. In contrast the PAO can observe the whole sky due to the differing methods of observing the air showers. The depth of the shower maximum varies by the composition e.g the depth of a proton shower is much larger than that of a heavy nuclei. Neither HiRes nor PAO want to be biased toward early or late developing showers and for this reason have to apply different cuts to the data. T his might explain the alteration of results. This theory has later been strengthened by the Telescope Array. [10] [11] [12]

2.1.4 Arrival Direction

To know the arrival directions of UHECR would tell us where the sources are located and consequently tell us which sources are probable. Because of UHECR's high velocity it would not be as affected by its propagation through galactic and extragalactic magnetic fields if the traveling distances are relatively small $\simeq 75$ pc. Thus to analyze the arrival directions with respect to a small deviation would theoretically give us the source of acceleration. PAO published a paper in 2007 stating that out of 27 events 18 arrival directions correlated with active galactic nuclei within an angle of 3.2°. HiRes performed a similar search for correlation but out of 13 events 2 such correlations could be found. Since then the statistical significance of the PAO correlation has decreased to about 38% of the events. Hence there is once again a disagreement between HiRes and PAO. The fact that it was PAO and not HiRes which showed a correlation is additionally puzzling considering the its result on the composition of UHECR. If they primarily consisted of heavier nuclei you would think that they were affected by the magnetic fields to a greater extent and accordingly show less of a correlation than HiRes. Nonetheless the arrival directions seem to be isotropic indicating extragalactic or undetected galactic sources. [4] [12]

3 Acceleration

According to the standard model the star in a super nova has three possible outcomes depending on its mass - either it collapses to a white dwarf, a neutron star or a black hole. With a preon model, however, there is a possibility for a new kind of star among the aforementioned. The preon star (PS) is formed in the same way a neutron star is formed but the nature of the star gives it very special characteristics. Instead of stabilizing with a radius $\sim$ 10 km like an ordinary neutron star, the preon star has a radius $\sim$ 1 m. This would yield a preon star mass close to $10^2 * M_\oplus$ ($M_\oplus$ being the Earth's mass $\simeq 6 * 10^{24}$ kg). The PS inherits a fraction of its progenitor's angular momentum though giving it an incredibly angular velocity. It also inherits the magnetic field of its progenitor. [1] [13]

Now assume there is a preon star with angular velocity ω, radius $R_(*) \simeq 1$ m and a magnetic field B = 10^8 T. In this report we will assume that the preon star follows the three layer model meaning that the star has a hadronic and leptonic crust and that the star works as a perfect conductor.[14] A rotating star with a dipolar magnetic field in a vacuum will develop an external quadrupole electric field ε. The maximal electromotive force will then be induced between one of the two poles of the star and the equator. The formula for the potential drop can then be written as [15] [16] [17]

$$\Delta\Phi = \frac{B\omega R_*}{2c} \tag{2}$$

It is apparent that unipolar induction by itself can not accelerate CR to its highest energies. Due to the small radius of the star the magnetic dipole moment gets too small and consequently restricting the viable energy extraction this mechanism of acceleration.

4 Discussion

One should not condemn unipolar induction in preon stars solely because of this article. First of all is the formula that I used to calculate the potential energy drop very crude and leaves plenty of room for future improvements. Second of all this article has shown us that the building of a magnetosphere in PS is possible and should therefore be explored further. It would be interesting for example to examine how the magnetosphere would behave in the vicinity of PS. Preon stars can still provide answers to many of the questions surrounding CR that is unanswerable with today's physics and should not be excluded from the CR research.

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