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Modeling of possible localized electron flux in cosmic rays with Alpha Magnetic Spectrometer measurements

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HIGHLIGHTS

- Use quantum discrete Boltzmann approach to capture the localized electron flux in cosmic rays.
- Dispersion relationship of Fermi gases in cosmic rays were calculated.
- We adopt the acoustic analog to explain the localized electron flux of cosmic rays.

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ABSTRACT

Discrete quantum Boltzmann model together with the introduction of an external-field-tuned orientation parameter as well as the acoustic analog are adopted to study the possible localization of electron (fermion) flux in cosmic rays considering the precision measurement with the Alpha Magnetic Spectrometer (AMS) on the International Space Station (ISS). Our approximate results match qualitatively with those data measured with the AMS on the ISS.

1. Introduction

Researchers (say, originally defined by Millikan in 1925 considering the discovery of outer space radiation penetrating the atmosphere by Hess in 1912) use *cosmic rays* to indicate all the energetic (charged) particles that reach Earth. Up to now it has been agreed that above particle rigidities (momentum divided by charge) of around 1 GeV (10^9 eV) interstellar particles (the fluxes are sufficiently high: typically a few cm^{-2} s^{-1}) have the energy spectrum over a vast energy range which is remarkably smooth with the famous *knee* at about 3×10^{15} eV and *ankle* at about 3×10^{18} eV. The particles with energy below the *knee* are definitely of Galactic origin and that above the *ankle* they are almost extra-galactic.

Quite recently precision measurements by the Alpha Magnetic Spectrometer (AMS) on the International Space Station (ISS) of the primary cosmic-ray electron flux in the range 0.5–700 GeV (10^9 eV) and the positron flux in the range 0.5–500 GeV are presented [1]. Two months latter a dedicated measurement of the cosmic ray ($e^+ + e^-$) flux up to 1 TeV with reduced statistical and systematic errors (based on the analysis of 10.6 million ($e^+ + e^-$) events collected by AMS on ISS) was also reported [2]. In brief summary the precision measurement of cosmic ray ($e^+ + e^-$) flux as a function of energy from 0.5 GeV to 1 TeV (10^{12} eV) indicates that the flux is smooth and reveals new and distinct information. No (specific) structures were observed. These results might generate widespread interest and discussions on the origin of high-energy positrons and electrons. However instead of performing an advanced study of the possible physical origin

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of the above mentioned progresses (e.g., from 30.2 GeV to 1 TeV, the flux can be described by a single power law with $\gamma_0 = -3.170 \pm 0.008(\text{stat} + \text{syst}) \pm 0.008)$ (energy scale) [2], in this work we simply take such observational indication as the main motivation to consider the possibility that the primary electron flux [1] gets localized.

Note that as a result of the significant cooling of the high energy electrons, only the relatively nearby electrons/positrons can reach the Earth. Hence the result of modeling electron/positron data does not depend on the dark matter distribution profile sensitively. To include the spatial and temporal discreteness of the sources of cosmic rays and to escape from the difficulties in considering detailed contributions from the dark matter, in this letter, we shall borrow from the acoustic analog [3] and the verified discrete quantum Boltzmann model [4] to study the possible localized cosmic electron flux (cf. Figs. 1(a) and 2(a) in [1]). In fact as a further study of plane-wave propagation (in dilute atomic as well as Boltzmann gases), considering the quantum analog of the discrete kinetic model [5] and the Ühling–Uhlenbeck collision term [6] which could describe the collision of a gas of dilute Fermi-, Boltzmann- or Bose-particles (via a Pauli *blocking factor* $\hat{\nu}$ within the form $1 + \hat{\nu}\bar{f} \equiv 1 + B$ with $\bar{f}$ being a normalized distribution function which gives us the number of particles in each infinitesimal range or per cell, say, a unit cell, in phase space) together with the (magnetic) field effects by tuning a parameter θ [4] , we shall investigate approximately the dispersion relations of plane waves propagating in dilute Fermi gases by the verified approach [4]. After using the acoustic analog [3] we can link our results with the electron (fermion) flux of the propagating cosmic rays which suffer collisions with the ambient matter in the Galactic interstellar medium (ISM). Our analytical results match qualitatively quite well with the cosmic electron flux measurements presented in Figs. 1(a) and 2(a) of [1].

2. Theoretical formulations

As originally proposed in [5,6] considering the fermi-statistic particles like an electron gas inside certain matter the collisions of the electrons with other particles (not electrons) are one possibility since by them the free (streaming) paths (during which the external forces are able to accelerate the electrons undisturbed) are interrupted whilst at an impact of electrons with each other the momentum gained by one electron is transferred to the next one. We start to introduce the general model below. The gas is presumed to be composed of identical particles of the same mass. The discrete number density (of particles) is denoted by $\bar{N}_i(\mathbf{x}, t)$ associated with the velocity $\bar{\mathbf{u}}_i$ at point $\mathbf{x}$ and time t. If only nonlinear binary collisions are considered, and considering the evolution of $\bar{N}_i$, we have

$$\frac{\partial \bar{N}_i}{\partial t} + \bar{\mathbf{u}}_i \cdot \nabla \bar{N}_i = J_i \equiv \sum_{j=1}^{M_t} \sum_{(k,l)} (\Lambda_{kl}^{ij} \bar{N}_k \bar{N}_l - \Lambda_{ij}^{kl} \bar{N}_i \bar{N}_j), \quad i = 1, \ldots, M_t, \tag{1}$$

where (k, l) are admissible sets of collisions [4,5]. We may also define the right-hand-side of above equation as

$$J_i(N) = \frac{1}{2} \sum_{j,k,l} (\Lambda_{kl}^{ij} \bar{N}_k \bar{N}_l - \Lambda_{ij}^{kl} \bar{N}_i \bar{N}_j), \tag{2}$$

with $i \in \Omega = \{1, \ldots, M_t\}$, and the summation is taken over all $j, k, l \in \Lambda$ (set of positive integers), where Λ_{kl}^{ij} are nonnegative constants satisfying [4,5]

(i) $\Lambda_{kl}^{ji} = \Lambda_{kl}^{ij} = \Lambda_{lk}^{ij}$,

(ii) $\Lambda_{kl}^{ij}(\bar{\mathbf{u}}_i + \bar{\mathbf{u}}_j - \bar{\mathbf{u}}_k - \bar{\mathbf{u}}_l) = 0$,

(iii) $\Lambda_{kl}^{ij} = \Lambda_{ij}^{kl}$.

The conditions defined for discrete velocities above are valid for elastic binary collisions such that momentum and energy are preserved. Collisions which satisfy the conservation and reversibility conditions which have been stated above are defined as admissible collisions.

With the introducing of the Ühling–Uhlenbeck collision term [4–6] in Eq. (1) or Eq. (2),

$$J_i = \sum_{j,k,l} \Lambda_{kl}^{ij} [\bar{N}_k \bar{N}_l (1 + \hat{\nu}\bar{N}_i)(1 + \hat{\nu}\bar{N}_j) - \bar{N}_i \bar{N}_j (1 + \hat{\nu}\bar{N}_k)(1 + \hat{\nu}\bar{N}_l)], \tag{3}$$

for $\hat{\nu} < 0$ we obtain a gas of Fermi-particles; for $\hat{\nu} > 0$ we obtain a gas of Bose-particles, and for $\hat{\nu} = 0$ we obtain Eq. (1). From Eq. (3), the model of discrete quantum Boltzmann equation for dilute atomic gases proposed in [4,5] is then a system of $2\eta(=M_t)$ semilinear partial differential equations of the hyperbolic type:

$$\frac{\partial}{\partial t}\bar{N}_i + \hat{\mathbf{v}}_i \cdot \frac{\partial}{\partial \mathbf{x}}\bar{N}_i = \frac{cS}{\eta} \sum_{j=1}^{2\eta} \bar{N}_j \bar{N}_{j+\eta} (1 + \hat{\nu}\bar{N}_{j+1})(1 + \hat{\nu}\bar{N}_{j+\eta+1}) - 2cS\bar{N}_i \bar{N}_{i+\eta} (1 + \hat{\nu}\bar{N}_{i+1})(1 + \hat{\nu}\bar{N}_{i+\eta+1}), \tag{4}$$

where $\bar{N}_i = \bar{N}_{i+2\eta}$ are unknown functions, and $\hat{\mathbf{v}}_i = c(\cos[\theta + (i-1)\pi/\eta], \sin[\theta + (i-1)\pi/\eta])$, $i = 1, \ldots, 2\eta$; c is a reference velocity modulus [4,5], S is an effective collision cross-section for the collision system, θ is the orientation starting from the positive x-axis to the $\hat{v}_1$ direction and could be thought of as a parameter for an orientation induced by external fields. The admissible collisions as $\eta = 2$ are $(\hat{\mathbf{v}}_1, \hat{\mathbf{v}}_3) \longleftrightarrow (\hat{\mathbf{v}}_2, \hat{\mathbf{v}}_4)$.