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Possible violation of the spin-statistics relation for neutrinos: Cosmological and astrophysical consequences

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Abstract

We assume that the Pauli exclusion principle is violated for neutrinos, and consequently, neutrinos obey the Bose–Einstein statistics. Cosmological and astrophysical consequences of this assumption are considered. Neutrinos may form cosmological Bose condensate which accounts for all (or a part of) the dark matter in the universe. "Wrong" statistics of neutrinos could modify Big Bang nucleosynthesis, leading to the effective number of neutrino species smaller than three. Dynamics of the supernova collapse would be influenced and spectra of the supernova neutrinos may change. The presence of neutrino condensate would enhance contributions of the Z-bursts to the flux of the UHE cosmic rays and lead to substantial refraction effects for neutrinos from remote sources. The Pauli principle violation for neutrinos can be tested in the two-neutrino double beta decay.

1. Introduction

What is the next surprise neutrinos will bring us? Pauli has introduced neutrino to resolve paradoxes of the beta decay, in particular, an apparent violation of the spin-statistics relation. Could the neutrino itself violate this relation? Does the particle invented by Pauli respect the Pauli principle? Do we have any indication to that?

The puzzle of cosmological dark matter (DM) remains with us already for more than a half of century but we still do not know what are the constituents of this mysterious substance. The commonly accepted point of view is that dark matter is made of new elementary particles governed by the laws of the old established physics. Here we will explore a different possibility: old particles and new physics. Namely we assume that Fermi statistics for neutrinos is violated

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and, if so, neutrinos with a fraction of eV masses, as observed in the oscillation experiments, could condense and make all cosmological dark matter, both cold and (a little) hot.

We suggest that Pauli exclusion principle is violated for neutrinos and therefore neutrinos obey (at least partially) the Bose–Einstein statistics. Of course, a possibility to explain the dark matter is not the only consequence of the spin-statistics violation. One can expect some effects of the violation in any environment where large densities or fluxes of neutrinos exist. That includes the early universe in the epoch of the Big Bang nucleosynthesis, the cores of collapsing stars, etc. Some consequences could be also seen in laboratory experiments (e.g., in the double beta decay).

Possible violation of the exclusion principle was discussed in a series of theoretical papers [1] though no satisfactory model has been proposed so far. (For a critical review see Ref. [2].) Experimental searches of the Pauli principle violation for electrons [3] and nucleons [4] have given negative results. It may happen however that neutrinos due to their unique properties are much more sensitive to the violation and it is in the neutrino sector the effects can be seen first. Neutrinos may also possess kind of mixed or more general statistics than Bose or Fermi ones [5].

The assumption of violation of the Pauli exclusion principle encounters immediately a number of problems. The spin-statistics theorem follows from the canonical quantization to ensure a positive definiteness of energy. It is not clear how to overcome this problem and how serious it is for neutrinos. The CPT theorem follows, in particular, from the normal relation between spin and statistics, therefore the suggested scenario may also violate the CPT invariance. Actually, a possible violation of the latter in neutrino physics is under an active study now, see, e.g., Ref. [6]. Furthermore, local observables would not commute and locality would be destroyed and Lorentz-invariance would be broken, see, e.g., books [7]. Still unitarity would remain if the Hamiltonian is hermitian. Last but not least, the spin-statistics violation in the neutrino sector is communicated due to the weak interactions to charged leptons and other fermions where the bounds are extremely strong. It is not clear if effects considered in this Letter are consistent with these bounds, which depends on particular mechanism of the violation.

In what follows we put aside discussion of these problems. Instead, taking pure phenomenological approach, we concentrate on cosmological and astrophysical consequences of the neutrino “bosonization” in an attempt to find interesting observable effects or to restrict such a possibility.

2. Bosonic neutrinos: context

The standard electro-weak theory puts the left-handed neutrinos and electrons into the same doublet and thus one would expect that neutrinos and electrons obey the same statistics. On the other hand, as we know, being the only neutral leptons, the neutrinos can have substantially different properties from those of the charged leptons. In particular, neutrinos can be the Majorana particles and induce the lepton number violation. The difference between the charged leptons and neutrinos is related to breaking of the electro-weak (EW) symmetry. The lepton number violation (in the context of seesaw mechanism) originates from very high scales.

Similarly, the neutrino sector might be a source of violation of the spin-statistics relation; this should also be connected to EW symmetry breaking and can originate from some high mass scale of nature. One may consider scenario where violation of the Pauli principle occurs in a hidden sector of theory related to the Planck scale physics, or strings physics. It could be mediated by some singlets of the standard model—(heavy) neutral fermions which mix with neutrinos when the EW symmetry is broken. Since only neutrinos can mix with the singlets, effects of the Pauli principle violation would be manifested first in neutrinos and then communicate to other particles. Also one can consider a possibility that the messenger of the Pauli principle violation is the light sterile neutrino. It has a small mixing with the active components, and this small mixing quantifies the degree of violation in the observable sector. In this way a small or partial violation of relation between spin and statistics might occur.

As in the case of lepton number, a violation of the spin-statistic relation for other particles can be suppressed by an additional power of a small parameter relevant for the violation in the neutrino sector. In fact, the high accuracy of the validity of Fermi statistics for