THE NEUTRINO SEA IN THE UNIVERSE AND THE STRUCTURE OF THE SPACE-TIME

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Observational and theoretical aspects of a possible presence of a neutrino background in the Universe are considered. Observable effects are related to the still open question of "missing mass" in clusters of galaxies. The presence of the neutrino sea can prove decisive in recognizing the proper structure of the space-time.

Since the first thorough analysis by Pontecorvo and Smorodinskii (1961), the existence of a background of hardly observable neutrinos and antineutrinos (in the following called briefly the "neutrino sea") in the Universe is considered in the framework of various cosmological models. Very often it is suggested that the neutrino density may exceed, by order(s) of magnitude, the density of observable matter. A recent summary of the various theoretical developments related to the concept of the neutrino sea is given in Chapter V of a booklet (Kuchowicz 1972); we wish to point here, in addition, to two aspects of this concept: one being of a more astrophysical, and the second — of a rather theoretical interest.

Let us start with the observational aspect. It has been known for many years that the masses of the clusters of galaxies obtained from the virial theorem by at least one order of magnitude exceed the masses resulting from the addition of all known constitutent galaxies. As there arises the question: Where is the missing mass, one might be interested in a search for hardly observable forms of matter in the clusters of galaxies. Van den Bergh (1969), however, presented negative results of an indirect observational search for missing mass in the form of collapsed objects with masses in the range from 10^8 to 10^{13} solar masses; this analysis was made for the Virgo Cluster. Studies by Allen (1969) at radio wavelengths gave little evidence of absorption by hydrogen in the radio spectra of galaxies in the same cluster. Thus intragalactic matter in the Virgo Cluster makes up only a small fraction of the required missing mass.

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Now the concept of the overall neutrino sea may be adapted to the search for the missing mass. Marx (1967) pointed already to the possible role of gravitating massive bodies in raising the local density of this sea. The original estimations were made in a Newtonian approximation, yet it is possible to extend them to general relativity. The effect goes into the same direction. It is possible to obtain a contribution to the total mass of the cluster from the neutrino sea, with the numerical value depending on the Fermi energy of the neutrino gas. When we assume a locally high enough Fermi energy of the neutrino sea, it is possible to obtain a contribution as large as it is necessary. With a small neutrino rest mass, as *e. g.* in the scale-invariant theory of leptons, the effect needs even a not too high value of the Fermi energy.

Though it is difficult to provide a direct experimental basis for a determination of the local density of the neutrino sea in our Galaxy, it is possible to point to the effect of this sea upon physical processes in our neighbourhood. Thus *e. g.* the interactions with the neutrino sea may provide a phenomenological model of the Fitzgerald-Lorentz contraction (Dudley 1972a), while the neutrino sea, treated like de Broglie's hypothetical subquantic medium, is even looked upon as being responsible for nuclear decays in a purely causal model (Dudley 1971, 1972b). The effect of the neutrino sea upon the radiative corrections in quantum electrodynamics was studied (Aurela 1969, 1970); it should be possible to exhibit space and time variations of the local values of the Lamb shift.

So far, we have considered only observational effects. Now, let us turn to the modifications in cosmological models which are necessary when the neutrino sea is taken into account. Till now, only the following modifications due to a possible large energy density of the neutrino sea have been studied: energy density and pressure of the neutrino gas were added explicitly to the corresponding quantities on the right-hand side of the Einstein field equations:

$$G_{\mu\nu} = -8\pi T_{\mu\nu} \tag{1}$$

(in which $G_{\mu\nu}$ is the geometrical Einstein tensor of the Riemannian space-time, $T_{\mu\nu}$ is the energy-momentum tensor, and all the physical constants are taken as equal to 1). The conclusion that one is able to derive from such a coarse treatment of the neutrinos is trivial: A high overall neutrino density makes it necessary to go over from open to closed Friedmann models. In such a treatment no effects following from the structure of the all--permeating neutrino field are considered though in the last years important theorems were derived for coupled neutrino-gravitational fields, and these can be applied now directly to cosmology.

In the abovementioned theoretical approach one analyzes two sets of equations: (*i*) the Einstein field equations (1), with the energy-momentum tensor due only to the neutrino field, and (*ii*) the Weyl equation for a two-component neutrino in the Riemannian space-time corresponding to Eq. (1). This geometric line of approach to the neutrino problem has yielded powerful theorems on the properties of "classical" (*i. e.* not-quantized) neutrino fields. All these developments are summarized recently in an extensive survey (Kuchowicz 1973) where references to the relevant papers may be found. Let us mention here the following interesting theorem (Trim and Wainwright 1971, Audretsch 1972):

Spherical symmetry of the space-time is not compatible with the presence of a neutrino field. If we would like to apply this to universes with a major contribution to the energy density resulting from the neutrino sea, we would be led to conclude that it is impossible to adopt purely spherically symmetric cosmological models. Hence, there would exist no neutrino universes in the class of standard Friedmann-like models.

Now, it has to be emphasized that perhaps there is no need for any departure from spherical symmetry of the Universe if a slight modification be made in Einstein's general theory of relativity: if in addition to the energy-momentum tensor we introduce from the beginning the density of spin as another fundamental physical tensor. The latter quantity, according to an old idea of Cartan (1922, 1923), should be related to the torsion tensor of the linear affine connection of the space. According to Trautman (1972), this may be looked upon as the natural extension of Einstein's original theory. Due to the lack of space we cannot give more detail on the Einstein-Cartan theory; the reader is referred to two recent summaries (Hehl 1973; Trautman 1972). We wish to point only to the fact that the abovementioned incompatibility theorem was proved only for Riemannian manifolds with a symmetric affine connection. One does not find any reason why this theorem should be generalized into the Einstein-Cartan theory where the affine connection no longer is symmetric. We do not know what will be the final result. Yet a simple, heuristic argument should be added: The neutrino sea should have a deeper imprint on the structure of the space-time than merely the choice between closed and open models of the Universe.

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