SHORT CONTRIBUTION

Relic Neutrinos with Non-Vanishing Rest Mass

G. Marx: Just after the Big Band, at the time when $T \geqslant 10^{11}$ K neutrinos were in thermal equilibrium with photons and with charged particles. After the decoupling epoch the number of neutrinos was frozen just like the number of photons. To-day the number of neutrinos must be comparable to the number of photons of the background radiation and about 10^8 times larger than the number of charged particles. During the expansion the charged particle mass density decreases like R^{-3} and the radiation density like R^{-4}. The law of change for the neutrino density depends on its rest mass.

Laboratory limits for neutrino masses are as follows: $0 \leqslant m(\nu_e) < 60$ eV; $0 \leqslant m(\nu_\mu) < 0.8$ MeV. It was first pointed out by Zel'dovich, that if $m_\nu \neq 0$ and if $kT \ll m_\nu$, the neutrino density drops as R^{-3}, and due to the high number density it may have a decisive influence on the expansion of the Universe. We integrated the life history of Universe up to the present temperature $T = 2.7$ K. The resulting values for Hubble shift H_0, deceleration q_0 and age t_0 are shown in Figure 1 for different values of the neutrino rest mass m. It can be seen that the present observational evidence gives an upper limit $m < 10$ eV, which is much better than the laboratory limit.

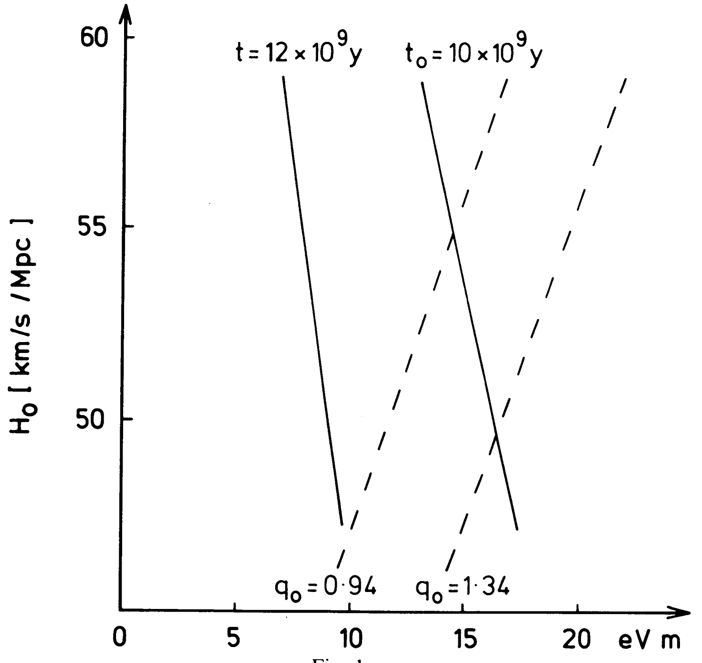

Fig. 1.

If we have a nonrelativistic gas of neutrinos in the Universe, its density is influenced by the gravitational pull of the clusters of galaxies. The neutrino halo around

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a cluster amplifies its gravitational field and helps to stabilize the cluster. We solved the self-consistent equation of the local gravitational potential of the cluster under the influence of the galactic mass density (considered to be an isothermal gas) and of the neutrino mass density (considered to be a Fermi gas with a small but positive Fermi energy). As a special example, let us consider the Coma cluster. By taking the central galactic density $\varrho_g(0)$ from observation, one can integrate our selfconsistent equation. One can calculate the Galaxy distribution $\varrho_g(r)$ and the density distribution $\varrho_\nu(r)$ of the neutrino halo for different assumptions about the neutrino mass m. In general, the neutrinos will dominate, if $m(mv/\hbar)^3 > \bar{\varrho}_{\mathrm{gal}}$, i.e. for $m > 1$ eV. Here v is the mean random speed of galaxies. The radius of the cluster R turns out to be proportional to $m^{1/2}$. A good fit with the observed shape of the Coma cluster can be obtained if $m \sim 0.5$ eV. (If $m > 1$ eV, the cluster shrinks too strongly. If $m < 0.1$ eV, the cluster is too diffuse or even unstable.)

We conclude that a background neutrino gas, comparable in number with the photon background, can solve the missing mass puzzle, if $m(\nu) \sim 1$ eV > 0. Expressed in a different way: The dynamics of the Coma cluster excludes the possibility of a ν rest mass $m > 1$ eV. This limit is 6 orders of magnitude stronger than the laboratory limit of $m(\nu_\mu)$.