PERTURBATIONS IN THE UNIVERSE WITH MASSIVE "...INOS"

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Weak interacting particles (WIPs): neutrinos (ν_e, ν_μ, ν_τ), the hypothetical photino ($\tilde{\gamma}$), the gravitino ($\tilde{g}$), etc., may have nonzero rest mass. This fact is extremely important for cosmology. WIPs do not annihilate in the very early Universe and their number is preserved. If they have a rest mass, their mass density may dominate in the Universe (1).

The present number density of some kinds of WIPs depends mainly on the number of kinds of ordinary matter fermion pairs (e^+e^-, p^+p^-, $n\bar{n}$, etc.), N_d that existed in the thermal bath at the moment of decoupling of the WIPs from the matter and radiation. N_d is the greater the earlier the WIPs decoupled and, during the cosmological expansion, these pairs' annihilation results in the temperature difference of WIPs and relict radiation. Their present density numbers are related as (2): $n_\gamma/n_w \approx N_d^{3/4}$ for $N_d >> 1$. More rigorous calculations are given in the following table:

	ν_e, ν_μ, ν_τ	?	?	?
N_d	1	10	10^2	10^3
n_γ/n_w	2.85	12	64	360

At the present time $n_\gamma \simeq 450$, so for $m_\nu \simeq 30$ eV (3), we have $\rho_\nu \simeq 160\ m_\nu \simeq 10^{-29}$ g/cm^3. This value may close the Universe. The clustering of the neutrinos together with matter may solve the problems of the small scale angular isotropy of the relict radiation and of the "hidden" mass in the rich galaxy clusters.

The problems connected with the heavy ...inos in the Universe have been considered in many recent publications (4,9). Here we want to stress that all the results obtained for neutrinos are valid also for other WIPs, if we take into account the different present number densities, according to the table. For example, the characteristic mass of a WIP cluster for large N_d is of the order of $M_{w(min)} \simeq 10^{15}\ M_\odot\ N_d^{-3/2}$ $(m_w/30\ \text{eV})^{-2}$ and the ratio of the WIP mass, M_w, to the ordinary mass M

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in the cluster is $M_w/M \simeq N_d^{-3/4}\ m_{w,eV}$ for $N_d^{3/4}$ eV $< m_w <$ 1 MeV, where $m_{w,ev}$ is m_w in eV-units (4,5).

There are some peculiarities in the law of the growth of the perturbations of the relativistic ordinary matter in the gravitational field of the WIP cluster. The equation describing this growth at the stage when WIPs are nonrelativistic and dominate the expansion has the form (5):

$$t^2\ddot{\delta}_m + \frac{2}{3}\, t\delta_m + \kappa^2(\delta_m - A) = 0 .$$

Here δ_m and δ_w (= $27A\kappa^2/8$) are Fourier-components of the relativistic matter and WIP density perturbations, $\kappa = ct/\bar{\lambda}\sqrt{3} \simeq t^{1/3}$, A = constant (gravitational potential of the WIP condensation), and $\bar{\lambda}$ is a perturbation scale. The solution of this equation is a sine wave oscillating around the constant value: $\delta_m = A + B \cdot \sin(3\kappa + \zeta)$; B, ζ = const. Let us remember that in the case of nonrelativistic plasma the equation for δ_m is analogous, but the second term is 4/3 t δ_m (10), which leads to the growth of perturbations instead of pure oscillations.

In a Universe with heavy neutrinos $\delta_{m1} \sim \delta_{\nu 1}$ at $t \sim t_1$, when neutrinos first become nonrelativistic. Then δ_m grows to $\delta_{\nu 1}\kappa^{-2} \geq \delta_{\nu 1}$, while δ_ν increases continuously as $t^{2/3}$. (Note that for $\kappa_1 >> 1$, perturbations damp [11].) After the hydrogen recombination at $t \sim t_2$, ρ_ν/ρ_m is constant and the radiation pressure no longer prevents the growth of δ_m, which thus grows rapidly to $\sim \delta_\nu$ (12). For $m_\nu \simeq$ 30 eV: $t_1 \simeq$ 300 years, $\delta_{m2} \simeq \delta_{\nu 1}\ (M/3 \cdot 10^{13}\ M_\odot)^{2/3} << \delta_{\nu 2}$, the characteristic mass of the usual galaxy cluster $\sim 3 \cdot 10^{13}\ M_\odot$ and the hidden mass of the neutrino halo $\sim 10^{15}\ M_\odot$, in agreement with observations.

The inequality $\delta_m << \delta_\nu$ at the epoch of the last scattering of relict quanta lowers the amplitude of small scale fluctuations of the relict radiation temperature: $\Delta T/T \simeq 10^{-5}\ (1 + Z_0)$ for $m_\nu \simeq$ 30 eV; the coefficient is 3 (10) times more for $m_\nu \simeq$ 3 eV(m_ν = 0), and less in the presence of heavy neutral leptons ($m_L \gtrsim$ 1 GeV) or primordial black holes. Z_0 is the moment of the beginning of the nonlinear evolution (δ_{m0} = 1) (13).

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Discussion

Bonometto: What is meant by $\Delta T/T$ in the results projected? Do you consider the significance to be due to an actual amplitude of the antenna beam? Which angles are being considered?

Novikov: The estimate $\Delta T/T$ in the paper means the average $\sqrt{<\Delta T^2/T>}$ (over all sky) for an angle of the order of the 10 arcmin.

Contopoulos: Does anyone know what are the present experimental limits for the mass of the neutrino?

Stecker: Recently R.W. Brown and I have compiled what we feel are the best present limits on τ_ν, which is really a function of photon energy $E \sim m_\nu/2$. We also point out a possible neutrino decay signal in the UV background which would give $m_\nu \sim 14$ eV and $\tau_\nu \sim 6 \times 10^{24}$ s. Such a short lifetime may imply that the neutrino is a composite particle (F.W. Stecker and R.W. Brown, 1982, Ap. J., 257, 1).

Novikov: The question was replied to by Szalay and Stecker.

[Szalay also responded to Prof. Contopoulos' question; we regret that his answer was not received. Eds.]