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IS THERE COSMOLOGICAL EVIDENCE FOR ADDITIONAL PARTICLES?

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An extended cosmological model of the early Universe with additional antisymmetric tensor particles is described. The cosmological effects of the additional particles, namely, additional interactions of the early Universe plasma with the tensor particles, a shift of the early Universe temperature-time dependence and the total energy density increase are discussed. The efficiency of the tensor particle interactions with early Universe plasma components and their corresponding cosmological time and temperature are determined.

KEY WORDS Cosmology, field theory model, tensor particles

1 INTRODUCTION

Recently a new model of electroweak interactions with additional antisymmetric tensor particles has been proposed (Chizhov, 1993). These particles manifest interesting and unusual properties (Avdeev and Chizov, 1994a, b; Chizov, 1995). Their presence may also lead to concrete experimental effects in different processes in elementary particle theory (Chizov, 1994a), and it can influence the early Universe processes as well. Applying the new model for analysis of some of the low-energy problems of the standard electroweak model $SU(2) \times U(1)$ showed that it could successfully solve them. Therefore, it is interesting to study the cosmological role of the additional tensor interactions. Such an investigation may also be useful for particle physics as far as the analysis of the standard cosmological model modification with additional antisymmetric particles may provide cosmological restrictions on the new physics investigated.

In this work we discuss first indications of tensor particles from low-energy physics experiments and a successful simultaneous explanation of a large number of experimental data by introducting tensor particles. Then we discuss qualitatively different effects due to the presence of tensor particles in the early Universe.

As shown below, the presence of additional tensor particles in the cosmological plasma leads to several qualitatively different effects: a shift of the temperature-time dependence in the early Universe, introduction of additional interactions for the components of the cosmological plasma and increase in the total energy density of the Universe. The analysis performed shows that the characteristic efficiency period of the tensor particle processes in the early Universe is very early and extremely short. Therefore, these three effects are very weak and they do not lead to major changes in the observable characteristics of the Universe, i.e. the presence of the considered antisymmetric tensor particles is allowed from the cosmological viewpoint.

2 TENSOR PARTICLES AND THE PROBLEMS OF LOW-ENERGY PHYSICS

There is a standard model of electroweak interactions (SM), which until recently was considered to be in absolute agreement with the experimental data (the experiments at LEP provide 1% accuracy of the most precise data on SM tests at high energies). However, recently *problems in low-energy physics* have been revealed.

(1) Three particles' semileptonic decay of the mesons (Bolotov, 1990), namely:

- semileptonic K_{e3} decay: $K^+ \rightarrow \pi^0 e^+ \nu_e$
- radiative $\pi_{e2\gamma}$ decay: $\pi^- \rightarrow e^- \bar{\nu}_e \gamma$

cannot be interpreted in the framework of the standard V–A interactions. The measured decay parameter values differ from that predicted in the SM by more than 3 standard deviations. There are indications of additional tensor terms, which are not natural for the SM.

(2) $K_L - K_S$ mass difference $\delta = (m_{K_L} - m_{K_S})/m_{K_L}$ value, predicted theoretically (Shifman, 1988), strongly differs from the experimentally measured one: $\delta^{\text{th}} \sim 0.6\delta^{\text{exp}}$.

The *field theory with tensor interactions*, proposed in Chizhov (1993, 1994a) provides a successful explanation of these experimental data and predicts new tensor interactions. The detailed analysis performed in a series of works showed that this theory is in good agreement with all experimental data, namely:

(1) it solves the π-decay problem (Poblaguev, 1990);

(2) it simultaneously solves the K- and π-decay problems (Chizhov, 1993);

(3) the antisymmetric tensor field, incorporated into the SM, provides the rest of the $K_L - K_S$ mass difference so that $\delta^{\text{th}} = \delta^{\text{exp}}$ (Chizhov, 1994a);

(4) the experimental data from pure leptonic decay is in accordance with tensor interactions (Chizhov, 1994b);

(5) the analysis allowing for tensor interactions in semileptonic τ decays (Gordina Nava and Lopez Castro, 1993) and pure leptonic τ decays (Chizhov, 1995) shows that the available experimental data allow the presence of tensor particles;

(6) both the data from semileptonic decays $n \to pe^-\tilde{\nu}_e$ (Poblaguev, 1990) and two particle π decay (Chizhov, 1993) allow terms.

3 ANTISYMMETRIC TENSOR PARTICLES IN THE EARLY UNIVERSE

3.1 The Tensor Particle Parameters

The mass M_T of the antisymmetric tensor particles $T_{\mu\nu} = -T_{\nu\mu}$ is introduced through the mechanism of spontaneous symmetry breaking (Englert and Brout, 1964) and is estimated to be about 300 GeV. The ratio of the coupling constant of the antisymmetric tensor particles with quarks and leptons f to the mass M can be estimated from the meson decay experiments (Chizhov, 1993). In our calculations we have used the value $f_T^2 = 6.3 \times 10^{-3}$. The particles under consideration are unstable and they have the following decay channels $T^- \to e^-\tilde{\nu}_e$, $T^+ \to e^+\nu_e$, $T^- \to d\tilde{u}$ and $T^+ \to u\tilde{d}$.

3.2 Cosmological Effects

The tensor particles are present at the early stage of the evolution of the Universe – the radiation-dominated stage (*RD*-stage). At this stage, according to the standard cosmological model, the expansion rate has the following dependence on the temperature

$$H = (8\pi^3 G/90)^{1/2}\sqrt{g_*}T^2, \tag{1}$$

where $G^{-1/2} = 1.22 \times 10^{19}$ GeV, and g_* is the effective number of the degrees of freedom $g_* = \sum_b g_b + \frac{7}{8}\sum_f g_f$. In the standard cosmological model at energies $E \geq 300$ GeV, the following particles are relativistic: quarks q, antiquarks $\tilde{q}$, leptons l, antileptons $\tilde{l}$, gauge bosons γ, Z^0, $W^\pm$, gluons g and Higgs particle H^0, $\bar{H}^0$, $H^\pm$. Then the effective number of the degrees of freedom is $g_* = 106.75$.

3.2.1 Shift of $T(t)$ dependence due to the presence of tensor particles

The theory of the antisymmetric tensor particles requires the introduction of two additional tensor doublets and one more Higgs doublet. This leads to an increase in the total effective number of the degrees of freedom at $T > 300$ GeV in the extended cosmological model with additional tensor particles: $g_*^T = 118.75$. This change leads to an increase in the expansion rate $H(t) = \left(\frac{8\pi^3 G}{90}\right)^{1/2}\sqrt{g_*^T}T^2$ and correspondingly to a decrease in the cosmological time at a given temperature. In other words the introduction of additional tensor particles into the cosmological plasma changes the time-temperature dependence in the early Universe due to the increase in the effective number of degrees of freedom.

3.2.2 *Direct interactions*

Apart from their influence on the expansion rate, the tensor particles have direct interactions with the cosmological plasma components. Here we present calculated total cross-section values for the characteristic interactions of the tensor particles in the early Universe plasma, namely:

(1) tensor particle creation and annihilation processes: $e^+ + e^- \rightarrow T^+ + T^-$, $\sigma_{\mathrm{PC}} \sim 2f_T^4/(\pi T^2)$;

(2) electron scattering by tensor particles: $T + e^\pm \rightarrow T + e^+$, $\sigma_s \sim f_T^4/(\pi T^2)$;

(3) tensor particle decay: $T \rightarrow e\nu$, $\Gamma_d \sim f_T^2 M_T \sim 1.9$ GeV.

The tensor particle interactions are effective when the characteristic rates of interaction are higher than the expansion rate $\Gamma_{\mathrm{int}} \geq H$. Otherwise, these particles drop out of a thermodynamical contact with the cosmological plasma because of the inefficiency of their interactions in comparison with the rate of change of the cosmological plasma parameters. The reaction rates are usually estimated as $\Gamma_{\mathrm{int}} \simeq \sigma_{\mathrm{int}} n$, where σ_{int} is a process total cross-section, and n is the concentration of particles. At energies higher than the tensor particle's mass, the cross-sections have the following behaviour $\sigma \sim E^{-2}$. Owing to this dependence, at high energies the tensor particles do not interact with the cosmological plasma, their reactions are frozen, and with decreasing temperature in the process of Universe expansion and decreasing characteristic energies, unfreezing (effective switch on) of the tensor particle reactions with the plasma components at $\Gamma_{\mathrm{int}} \leq H$ occurs. The temperature of the unfreezing of a given interaction $i \rightarrow f$ is defined as

$$T^2 = (90/8\pi^3 G)^{1/2} g_*^{-1/2} n\sigma_{if}, \qquad (2)$$

and the corresponding cosmological time is

$$t = 2.42/(\sqrt{g_*}T^2[\mathrm{MeV}])\ \mathrm{s}. \qquad (3)$$

In this way, on the basis of the analysis of the main interactions of antisymmetric tensor particles with other components of the cosmological plasma, calculations of characteristic temperatures and cosmological moments of the interactions of these particles in the early Universe have been made.

Particle creation. In the expanding Universe the creation of pairs of tensor particles is effective at temperatures higher than the rest mass of the particles and lower than the temperature of particle creation T_c, at which the rate of the processes of tensor particle creation becomes higher than the expansion rate: $2m \leq T \leq T_c$.

The temperature below which the tensor particle creation becomes effective and its corresponding cosmological time are: $T_c = 1.6 \times 10^{14}$ GeV, $t_c = 8.1 \times 10^{-36}$ s.

Electron scattering by a tensor particle. A typical example of electron scattering by tensor particles is their interaction with electrons and positrons of the cosmological plasma. The tensor particle interaction with fermions becomes effective at $T \leq T_s$ and times greater than t_s where $T_s = 8.8 \times 10^{13}$ GeV, $t_s = 2.9 \times 10^{-35}$ s.

Annihilation of tensor particles. The annihilation of tensor particles becomes possible at temperatures $T \leq T_a$ and times $t \geq t_a$, where $T_a = 1.1 \times 10^{14}$ GeV, $t_a = 1.9 \times 10^{-35}$ s. The annihilation of the particles ends at the moment $t_{\rm ta} = 2.42/(\sqrt{g_*}T_{\rm ta}^2[\text{MeV}])$ s $= 6.2 \times 10^{-13}$ s, defined from equation (3), where $T_{\rm ta}$ is made equal to $2M$.

Tensor particle decay. The decay width of the tensor particles is $\Gamma \sim f^2 M = 1.89$ GeV. The corresponding cosmological time and the decay temperature are $\tau_d = 3.5 \times 10^{-25}$ s, $T_d = 8.0 \times 10^9$ GeV. It is interesting to compare the characteristic moment of the particleź decay t_d and the time of their full annihilation. As far as $t_d \ll t_{\rm ta}$ the tensor particles mainly decay. The effective time interval corresponding to the temperature interval $T_d \leq T \leq T_c$ is very narrow: $\Delta t \sim 3.5 \times 10^{-25}$ s.

3.2.3 Total energy density increase

Analysis of the possibility of tensor particle dominance in the total energy density of the Universe

$$\rho_{\rm tot} = \frac{\pi^3}{30} g_*^T T^4,$$

at some period of its evolution, shows that in the case of tensor particles deviating from equilibrium with the cosmological plasma being relativistic, their dominance is, in principle, possible at temperatures lower than T_m and time later than t_m, where $T_m = 1.0$ GeV, $t_m = 2.1 \times 10^{-7}$ s. However, bearing in mind that the annihilation and the decay time values of these particles are much smaller $t_d \ll t_{\rm ta} \ll t_m$, it is obvious that the tensor particle dominance stage cannot be realized. Therefore, from the requirement that their density should not be greater than the critical Universe density for a given epoch, $\rho_T(t) \leq \rho_{\rm crit}(t)$, it is not possible to put cosmological constraints on tensor particle characteristics.

4 CONCLUSIONS

The above analysis of the cosmological place of antisymmetric tensor particles shows that their direct interactions with the components of the high-temperature plasma of the early Universe are effective on the interval 8.1×10^{-36} s $\leq t \leq 3.5 \times 10^{-25}$ s. The beginning of this time interval is defined from the moment of unfreezing of the characteristic reactions of the tensor particles with the rest components of the cosmological plasma, while the end of this time interval is the moment of their decay. Thus, the interval of efficiency of tensor particle interactions with the components of early Universe plasma is very early and extremely short! Therefore, obviously their influence on the processes proceeding in later epochs, like cosmological nucleosynthesis and recombination, is hardly noticeable. The tensor particles cannot dominate in the total energy density of the Universe. Their influence is reduced mainly to a slight increase in the expansion rate, due to the change in the effective number of degrees of freedom in comparison with the standard cosmological model.

The analysis of the cosmological role of the tensor particles performed does not impose essential cosmological restrictions on the parameters of the tensor particles on the basis of the observed characteristics of our Universe. A subject of further investigation on antisymmetric tensor particles from the cosmological standpoint could be a more detailed analysis of the problem of interactions of tensor particles with all the early Universe plasma components, as well as the study of the possible role antisymmetric tensor particles may play in inflationary cosmological theories and in cosmological models with a cosmological constant.

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