Chiral Tensor Particles in the Early Universe - Present Status

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In this work an update of the cosmological role and place of the chiral tensor particles in the Universe history is provided. We discuss an extended model with chiral tensor particles. The influence of these particles on the early Universe evolution is studied. Namely, the increase of the Universe expansion rate caused by the additional particles in this extended model is calculated, their characteristic interactions with the particles of the hot Universe plasma are studied and the corresponding times of their creation, scattering, annihilation and decay are estimated for accepted values of their masses and couplings, based on the recent experimental constraints. The period of abundant presence of these particles in the Universe evolution is determined.

Keywords: chiral tensor particles; early Universe; particle interactions.

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1. Introduction

The chiral tensor (ChT) particles were first predicted from theoretical considerations\cite{1} as an extension of Standard Model. Namely, these new type of spin-1 particles complete the set of Yukawa interactions and allow to realize all possible irreducible representations of the Lorentz group. These chiral tensor particles belong to the fundamental representation of $SU(2)_L$ group of the Standard Model. The ChT particles are boson particles and they were predicted to be the carriers of new interaction, however in contrast to the gauge bosons, they have only chiral interactions with the known fermions, through tensor anomalous coupling. For more detail see the reviews\cite{2,3}

Besides, the inclusion of the ChT particles helps to solve the hierarchy problem\cite{4,5}

At present the search of the chiral bosons is conducted by the international collaboration ATLAS at the Large Hadron Collider at CERN. After the first run of
the LHC experimental constraints on their masses were obtained\cite{7,8}.

The cosmological influence of ChT particles has been first considered by Kirilova et al., 1995\cite{9} and in later publications\cite{10,11,12}. It was found that the new ChT particles contribute to the matter tensor in the right-hand side of the Einstein–Hilbert equation, increasing the Universe density and changing the dynamical evolution of the Universe. Besides, possible direct interactions of ChT particles were proposed with the particles present at the early stage of the Universe evolution. The dynamical effect and the interactions of ChT particles with the constituents of the early Universe plasma were explored. A cosmological constraint on the strength of their interaction $G_T < 10^{-2} G_F$ was obtained\cite{11} on the basis of BBN considerations\cite{13}. Hence, the ChT particles interactions are expected to be centi-weak, which is in accord with the theoretical and experimental findings.

Here we reconsider the processes involving ChT particles, namely their dynamical effect and their interactions in the early Universe plasma using the latest experimental constraints on their characteristics, that have been obtained at ATLAS.

The next section describes the characteristics of the chiral tensor particles. The third section presents an update of the cosmological influence of ChT particles, namely an update of their creation, decay, annihilation and scattering processes and of the characteristic scale of their typical processes and their dynamical effect. The last section presents the conclusions.

2. Chiral Tensor Particles Characteristics

ChT particles are described by an antisymmetric tensor fields of a rank two. They have a chiral charge and change the fermion chirality. They have an anomalous (Pauli) interaction with matter.

The ChT particles are introduced as doublets $(T_{\mu\nu}^+ T_{\mu\nu}^0)$, like the Higgs particles. The possibilities for new chiral anomalies are avoided by introducing an additional doublet $(U_{\mu\nu}^0 U^\mu_\nu)$ with an opposite chiral- and hypercharge. Correspondingly also the Higgs sector is increased: it becomes $(H_1^+, H_0^1)$, $(H_2^0 H_2^-)$.

As in the Standard Model a Higgs-like mechanism is used to provide mass to the massless tensor particles, which have just longitudinal degrees of freedom. The role of the Higgs field is played by a triplet, denoted by $C_{\mu}$, and singlet gauge vector particles or by four $SU(2)_L$ singlets (depending on the chiralities of the ChT particles), $P^i_\mu$ $(i = 1, ..., 5)$, which allow them to acquire transverse physical degrees of freedom.

To avoid flavor violation in the neutral sector due to the doubling of doublets it is assumed that the doublets $H_1$ and $T_{\mu\nu}$ interact only with down-type fermions, while the doublets $H_2$ and $U_{\mu\nu}$ – with up-type ones\cite{11}.

2.1. Chiral tensor particles degrees of freedom

In the extended model with ChT particles their effective number of the degrees of freedom changes. We have recalculated the degrees of freedom, using consistent
quantization of ChT fields with pyramid of ghosts, as proposed by Chizhov and Avdeev.\textsuperscript{15} The presence of the two additional tensor doublets, the triplet and singlets gauge vector particles and the extra Higgs doublet increases the total effective number of the degrees of freedom by

\[ g_{C\!k\!T} = g_T + g_U + g_C + g_P + g_H = 4 + 4 + 6 + 10 + 4 = 28. \]

Hence, the total number of the degrees of freedom, while the additional particles are relativistic, is:

\[ g_* = g_{SM} + g_{C\!k\!T} = 106.75 + 28 = 134.75. \] (1)

### 2.2. Chiral tensor particles masses

The presence of the vacuum expectation values of the two different Higgs doublets leads to different masses for the tensor particles interacting with up- and down-type fermions. Present experimental constraints on the masses of the tensor particles interacting with down type fermions at 95\% CL are: \( M_{T^0} > 2.85 \text{ TeV} \) and \( M_{T^+} > 3.21 \text{ TeV} \) which are considerably higher than assumed in previous publications. Constraints on the masses of tensor particles interacting with up-type fermions are not available yet.

### 3. Cosmological Effects of the Chiral Tensor Particles

We reconsider the following cosmologically effects of ChT particles: their influence on Universe expansion rate due to the increase of the energy density and ChT particles direct interactions with fermions.

#### 3.1. ChT particles influence on the Universe expansion

Due to the additional particles in the extended model with ChT particles, the energy density of the Universe is increased in comparison with the Standard Cosmological Model case:

\[ \rho = \rho_{SCM} + \rho_{C\!k\!T}. \] (2)

where the ChT particles contribution, while they are relativistic, is: \[\rho_{C\!k\!T} = \frac{\pi^2}{30} g_{C\!k\!T} T^4, \] \( T \) is the photons temperature. Hence, the expansion rate of the Universe is increased:

\[ H = \sqrt{8\pi^3 G_N g_* / 90} T^2 \] (3)

\( g_* \) is the total number of the effective degrees of freedom from (1). The temperature-time dependence is changed, correspondingly, \( t \sim 1/(\sqrt{g_*} T^2) \).
3.2. *ChT* particles interactions in the early Universe

The tensor particles are supposed to have interactions with the fermions.

At early epoch while *ChT* particles were relativistic their cross sections decrease with energy increase, $\sigma \sim E^{-2}$, and hence *ChT* particles have been frozen. With the decrease of the Universe temperature in the course of the expansion the mean energy of particles also decrease and *ChT* interactions unfreeze when their characteristic interaction rates $\Gamma_{\text{int}} \sim \sigma n$ become greater than the expansion rate $H(T)$. The temperature of unfreezing $T_{\text{eff}}$ of an interaction $i \rightarrow f$ is estimated from:

$$\sigma_{if}(T_{\text{eff}})n(T_{\text{eff}}) = H(T_{\text{eff}})$$

(4)

The corresponding cosmic time in seconds is:

$$t_{\text{eff}} \approx \frac{2.42}{\sqrt{g_\ast}} T_{\text{eff}}^2$$

(5)

where $T_{\text{eff}}$ is in MeV.

Using the recent experimental constraints on the characteristics of *ChT* particles, we provide an update of their creation, scattering, annihilation and decay processes and estimate the characteristic temperatures and cosmic times of these processes in the early Universe.

*ChT* particles creation from fermion-antifermion collisions

The creation of pairs of longitudinal tensor particles from fermion-antifermion collisions has a cross-section:

$$\sigma_c \approx \frac{g_T^4 \ln(T/v)}{4^3 \pi T^2}$$

(6)

where $g_T$ is the *ChT* particles coupling and the Higgs vacuum expectation is $v \approx 246$ GeV.

We have found that the tensor particle creation processes unfreeze when the Universe temperature falls below $T_c$, where

$$T_c \approx 1.83 \times 10^{17} \text{ GeV}$$

(7)

This temperature is slightly higher (by an order of magnitude) than previously estimated.
Thus, the ChT particles are created in the period when the Universe temperature falls from $T_c$ till $T \sim 2M_T$. The corresponding time of the unfreezing of ChT particles creation is: $t_c \approx 6 \times 10^{-42}$ s. It is earlier than previously estimated.

**Fermions scattering on ChT particles**

The cross-section of fermions scattering on ChT particles is given by:

$$\sigma_s \approx \frac{\pi g^2}{3 \times 4^3 \pi T^2}$$

This process unfreezes at

$$T < T_s \approx 1.89 \times 10^{15} \text{ GeV}$$

$T_s$ is slightly changed (higher by an order of magnitude) compared to previous estimation. The corresponding cosmic time period is $t > t_s \approx 5.86 \times 10^{-38}$ s.

**ChT particles annihilations**

We have calculated that tensor particles annihilations proceed till

$$t_a \approx 2.42/(\sqrt{g^*} T_a^2 \text{[MeV]}) \text{ s}$$

where $T_a = 2M_T$. In case $M_T = 3$ TeV is assumed $t_a \approx 5 \times 10^{-14}$ s. I.e. annihilation processes stop earlier than estimated in previous works, which considered smaller ChT particles masses.

**ChT particles decays**

In the hot Universe plasma while relativistic the ChT particles do not effectively decay because their states are repopulated by the inverse decay by the particles of the hot plasma, so their density for $T > M_T$ is close to their equilibrium value. With the decrease of the Universe temperature during its expansion the ChT particles become non relativistic. Then the inverse decay processes can be neglected. The cosmic time corresponding to the decay of ChT particles at $T \sim M_T$ is $t_d \approx 2.42/(\sqrt{g^*} T_d^2 \text{[MeV]})$ s, where $T_d \sim M_T$. For $M_T = 3$ TeV $t_d \approx 2 \times 10^{-13}$ s.

The decay width of the tensor particles at rest is estimated to be:

$$\Gamma \approx g^2 T^4 M_T/4\pi \approx 102 \text{ GeV.}$$

This width is considerably larger (an order of magnitude) than the estimated in earlier works. The lifetime is also changed, namely, $\tau = 6.5 \times 10^{-27}$ s.
Having in mind that the decay time is later than the annihilation time, it can be concluded that the main part of the ChT particles disappear from the cosmic plasma due to their annihilations at \( t \sim t_a \) and the rest decay rapidly soon after that at \( t \sim t_d \). Hence, the period of their abundant presence in the hot Universe is the period from the time of their creation to the time of their annihilation:

\[
6 \times 10^{-42} \, \text{s} < t < 5 \times 10^{-14} \, \text{s}.
\]

The corresponding energy range is from \( 1.8 \times 10^{17} \, \text{GeV} \) to \( 6 \times 10^{3} \, \text{GeV} \).

The ChT particles disappear at early epoch and, therefore, they cannot disturb Big Bang Nucleosynthesis and Cosmic Microwave Background formation epoch. On the other hand ChT particles are present at energies typical for inflation, Universe reheating, lepto- and baryogenesis. The extended model with ChT particles proposes new source for CP-violation and may present a natural mechanism for leptogenesis and baryogenesis scenarios.

4. Conclusion

We discuss an extended Beyond Standard Model of Particle Physics and Cosmology with new ChT particles. The influence of these particles on the early Universe is studied.

At present the search of these particles is conducted by the ATLAS Collaboration at LHC. First experimental results provided constraints on the tensor particle masses and couplings. Using current experimental and theoretical findings we calculated the ChT particles characteristic processes: creation, scattering, annihilation and decay.

The characteristic interactions of the chiral tensor particles in the early Universe plasma were found to be noticeably different than previously calculated. The time interval of abundant presence of ChT particles in the Universe evolution is determined. It lasts from the time of their creation till their annihilation, namely: \( 6 \times 10^{-42} \, \text{s} < t < 5 \times 10^{-14} \, \text{s} \). The corresponding energy range is from \( 1.8 \times 10^{17} \, \text{GeV} \) down to \( 6 \times 10^{3} \, \text{GeV} \), which according to us is very promising for theoretical speculations involving ChT particles concerning inflationary models, reheating scenarios, baryogenesis, leptogenesis scenarios, etc.

The speeding up of the Hubble expansion due to the density increase caused by the introduction of the new particles and the change of the temperature-time dependence are estimated.

The discussed model of BSM physics with additional chiral tensor bosons is allowed from cosmological point of view and hopefully its unique predictions will be tested at the new run of LHC.

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