Cosmological implications of a class of $SO(10)$ models

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The cosmological implications of a class of $SO(10)$ models are discussed. In particular we show how a good prediction for neutrino masses is obtained in order to fit with the MSW mechanism to explain the solar neutrino flux deficit and with the predicted amount of the dark matter hot component. A possible scenario for baryogenesis is also considered.

1. INTRODUCTION

It is well known that the electroweak standard model is now established with incredible high precision. The dream of many physicists about a higher degree of unification, realized by assuming a larger gauge group at higher energies, cannot be tested by using the usual accelerator approach.

The typical signature of GUT theories, the baryonic matter instability, has not been found so far but the lower limit on the proton lifetime set the typical unification scale at $10^{15} - 10^{16}$ GeV, which is incredibly high with respect even to next generation of earth experiments. However, the big progress in astronomical observations gives a chance to use the history of the universe as a natural device to look for some evidence for an era, in the early stage of the universe, governed by a larger symmetry. In this respect it is worth to study all cosmological implications of GUT models at high scales (inflation, topological defects, baryogenesis) and low scales (neutrino masses).

2. A CLASS OF $SO(10)$ MODELS

It is quite a general result that the breaking of $SO(10)$ down to the standard model group should proceed via an intermediate symmetry stage. In order to identify the possible directions for spontaneous symmetry breaking, one has to classify the components, in the smallest irreducible representations (IR) of $SO(10)$, that are invariant under $SG$. From Table 1 it is seen that for all IR, but the 144, the little group of the SG-singlet is larger than SG.

The use of 16, 126 and 144 representations would lead to the result that, as in the minimal $SU(5)$ model, the three SG running coupling constant would not meet at one point. Considering the 45 representation, one can show instead that the only non-trivial positive definite invariant with degree $\leq 4$ (as necessary in order to have
Table 1
Classification of the Higgs $SG$-invariant components in the lower irreducible representation of $SO(10)$. $SG$ is the standard group while $D$ is the left-right discrete symmetry [5].

| IR       | $SG$                                      | Symmetry                  |
|----------|-------------------------------------------|---------------------------|
| $16\chi$ | $SU(5)$                                   |                           |
| $\alpha_1$ | $SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \times D$ |                           |
| $\alpha_2$ | $SU(4)_{PS} \otimes SU(2)_L \otimes U(1)_{B-L} \times D$ |                           |
| $\lambda$ | $SU(4)_{PS} \otimes SU(2)_L \otimes SU(2)_R \times D$ |                           |
| $\phi_1$ | $SU(3)_c \otimes SU(2)_L \otimes U(1)_{B-L} \times D$ |                           |
| $\phi_2$ | $SU(4)_{PS} \otimes SU(2)_L \otimes SU(2)_R$ |                           |
| $\phi_3$ | $SU(3)_c \otimes SU(2)_L \otimes U(1)_{T_3R} \otimes U(1)_{B-L}$ |                           |

a renormalizable potential) that one can build has its minimum in the $SU(5) \otimes U(1)$-invariant and its maximum in the $(SO(8) \otimes SO(2))$-invariant directions [3], so that it is not possible to construct a Higgs potential with minimum along the $\hat{\alpha}_1$ or $\hat{\alpha}_2$ directions. Moreover, the $\phi_3$ component in the 210 representation corresponds to a direction with neither $SU(4)_{PS}$ nor $SU(2)_R$ in the little group.

The previous considerations lead us to the following four choices for $G$

$SO(10)$

(i) $\hat{\phi}_1 \rightarrow SU(4)_{PS} \otimes SU(2)_L \otimes SU(2)_R \times D$

(ii) $\hat{\phi}_1 \rightarrow SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \times D$

(iii) $\hat{\phi}_2 \rightarrow SU(4)_{PS} \otimes SU(2)_L \otimes SU(2)_R$

(iv) $\hat{\phi}_3 \rightarrow SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$

where $\hat{\phi}_4 = \cos \theta \hat{\phi}_1 + \sin \theta \hat{\phi}_2$. The spontaneous symmetry breaking to $SU(3)_c \otimes U(1)\ell_Q$ is then realized, in all four cases, using the $\hat{\omega}$-component of a $126 \oplus 126$ representation, and a combination of the $SU(3)_c \otimes U(1)\ell_Q$-invariant components of two 10’s, in such a way to avoid the bad relation $m_t = m_b [5]$. The previous four possibilities have been studied in the Refs. [3]-[14]. We only report here for brevity the results for the case (iv), which seems to be the more promising, for the mass scales corresponding to the two symmetry breaking stage:

$$M_R \leq 1.2 \cdot 2.5^{0.1_1} \cdot 10^{11} \text{ GeV},$$

$$M_X = 1.9 \cdot 2.0^{0.1} \cdot 10^{16} \text{ GeV}.$$  

3. SOME COSMOLOGICAL IMPLICATIONS

In the framework of the well known see-saw mechanism [11], the upper limit for $M_R$ gives rise to the following inequalities for $m_{\nu_e}$ and $m_{\nu_\mu}$:

$$m_{\nu_e} \geq \frac{34.1 g_{2R}(M_R)}{f_i(M_R)} \text{ eV},$$

$$m_{\nu_\mu} \geq \frac{2.4 \cdot 10^{-3} g_{2R}(M_R)}{f_i(M_R)} \text{ eV},$$

where $g_{2R}$ and $f_i$ are the $SU(2)_R$ gauge coupling constant and the Yukawa coupling of the $126 \oplus 126$ to the i-th family respectively, and we have used a value of the top quark mass $m_t = 176$ GeV. For reasonable values of $g_{2R}$ and $f_i$, Eqs. (4) imply a substantial contribution of $\nu_e$ to the dark matter in the universe and a $m_{\nu_\mu}$ relevant for the MSW solution of the solar-neutrino problem [2].

Another interesting prediction of this class of $SO(10)$ models is a dynamical explanation of the presently observed baryon asymmetry. Indeed, these models can satisfy the three necessary conditions stated by Sakharov [3]: i) the $SO(10)$-gauge bosons mediate interactions which may lead to $B$-violations; moreover, at the scale $M_R$, $B \rightarrow L$ violating interactions may produce a net asymmetry in this quantum number which cannot be washed out by the baryon number violating electroweak anomalous effects, which are active at lower scales; ii) at the intermediate scale, $C$ and CP symmetry are broken [3]; iii) non-equilibrium conditions can be implemented if the masses of the Higgs particles satisfy certain conditions.

A scenario in which i), ii), and iii) are realized is discussed in Ref. [14], in which the $SO(10)$ model with $G = SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$ is

1No $C$-odd quantum number asymmetries can be generated until $C$ and CP symmetry remain unbroken, and this happens only at $M_R$ since the intermediate group has the same rank of $SO(10)$ [14].
considered. A non-zero value of the asymmetry \( \Delta(B - L) \) is produced at \( T \sim M_R \) by the \( B - L \)-violating decays \( \tilde{\phi} \rightarrow \tilde{\psi} f \nu_L \), where \( \tilde{\phi} \) are some Higgs multiplets of the 210 described in Ref.[14], \( \tilde{\psi} \) are the Higgs of the 126 which have mass of order \( M_R \), and \( f \) is a fermion. The knowledge of the mass spectrum of the Higgs scalars allowed to verify the possibility to have an overabundant population of \( \tilde{\phi} \) at \( M_R \), expressed by the inequalities \( 10^{12} \text{GeV} \leq m_{\tilde{\phi}} \leq 4 \cdot 10^{14} \text{GeV} \), where the first and second inequality correspond to the condition that the annihilation and decay processes respectively are "frozen out". If no \( B - L \)-violating phenomena are active at lower temperatures, the stored \( \Delta(B - L) \) is transformed in \( \Delta B \) by the sphaleronic processes leading to a value for the photon to baryon ratio in agreement with the observed one \( \eta_B = (4 \div 7) \times 10^{-10} \). Notice that the fact that an asymmetry in \( B - L \) is produced, which cannot be washed out by the low-energy \( B \) and \( L \) anomalous violating interactions, is quite crucial. In the usual \( SO(10) \) baryogenesis scenarios, in fact, it was assumed that \( B \)-violating interactions would provide the observed value for the baryon to photon density ratio. The presence of sphalerons, however, would completely erase any asymmetry produced in such a way.

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