



13 What Cosmology Can Come From the Broken SU(3) Symmetry of the Three Known Families?

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Abstract. The question, why there are three quark-lepton families, cannot find answer in the Standard model. Extension of the symmetry of the Standard model by local gauge SU(3) symmetry of families involves new physics at high energy scales. Even elusive from direct experimental probes such construction can be tested in the combination of physical, astrophysical and cosmological signatures, in which cosmological probes play important role. In the case of chiral local gauge SU(3)_H family symmetry such probes not only provided complete test of the model, but also demonstrated a possibility to describe the physical basis of modern cosmology, involving inflationary models with baryosynthesis and nonbaryonic dark matter. We formulate the programme of studies of cosmological impact of broken local gauge vector-like SU(3)_F family symmetry.

Povzetek. Standardni model ne more odgovoriti na vprašanje, zakaj obstajo tri družine kvarkov in leptonov. Razširitev simetrij standardnega modela z lokalno umeritveno družinsko simetrijo SU(3) ponudi nove možnosti za opis dogodkov pri visokih energijah. Lokalna umeritvena družinska simetrija SU(3)_H ponudi drugačen opis vesolja, ko so v model vključeni tudi inflacija, sinteza barionov in nebarionska temna snov. Delo predstavi program študija kozmoloških posledic zlomljene družinske simetrije SU(3)_F.

13.1 Introduction

The structure of the ordinary matter does not need more than one (first) family. We need quarks to build nucleons, electrons to bind with nuclei in neutral atoms and we have to add neutrino as a necessary element of beta processes, in which all the chemical elements of Mendeleev periodic table can be formed. However, the Nature gives us three families - symmetric by their interactions and asymmetric in their mass pattern. Extending the symmetry of the "Standard Model" (SM) by family symmetry and putting this additional symmetry on the same local gauge

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symmetry footing as in the Standard model we immediately find that though the family symmetry breaking scales in quark and lepton masses are within the range of electroweak symmetry breaking the absence of Flavor Changing Neutral Currents (FCNC) makes us to consider much larger scale of symmetry breaking for horizontal gauge bosons, which should be much heavier, than W and Z. To solve this problem one should assume the existence of heavy partners for ordinary quarks and leptons. These heavy particles should get their masses from the same Higgs mechanism, which makes very massive horizontal bosons, while mixing of these heavy partners with ordinary quarks and leptons reflects the pattern of family symmetry breaking in the mass hierarchy of quarks and leptons of the three known generations. Cosmological impact of this construction provides additional source of information on possible parameters and signatures of a family symmetry model. Here after brief review of the cosmology of horizontal unification, developed by [1,2] (see [3–5] for review and references) we turn to the approach by [Albino] and formulate open questions for successive study of cosmological impact of his vector-like approach to a gauge model of broken family symmetry.

13.2 Cosmology of chiral SU(3)_H symmetry of known families

The existence and observed properties of the three known quark-lepton families appeal to the broken SU(3)_H family symmetry [1,8,9], which should be involved in the extension of the Standard model. It provides the possibility of the *Horizontal unification* in the “bottom-up” approach to the unified theory [2]. Even in its minimal implementation the model of *Horizontal unification* has demonstrated its principal possibility to reproduce the main necessary elements of the modern cosmology. It provided the physical mechanisms for inflation and baryosynthesis as well as it offered unified framework to describe Cold, Warm, Hot and Unstable Dark Matter candidates. Methods of cosmoparticle physics [3,4] have provided the complete test of this model, proving such possibility for any physical model, hiding its basis in super high energy scales.

13.2.1 Horizontal hierarchy

The approach of Refs. [1,2,8,9] (and its revival in Refs. [10–12]) followed from the concept of local chiral gauge symmetry SU(3)_H, first proposed by Chkareuli[13]. Under the action of this symmetry the left-handed quarks and leptons transform as SU(3)_H triplets and the right-handed as antitriplets. Their mass term transforms as $3 \otimes \bar{3} = 6 \otimes \bar{3}$ and, therefore, can only form in the result of horizontal symmetry breaking.

This approach can be trivially extended to the case of n generations, assuming the proper SU(n) symmetry. For three generations, the choice of horizontal symmetry SU(3)_H seemed to be the only possible choice because the orthogonal and vector-like gauge groups could not provide different representations for the left- and right-handed fermion states. However, it turns out [Albino] that vector-like implementation for family SU(3)_F is also possible, what we discuss in the successive sections.

The mass hierarchy between generations was related to the hypothesis of a hierarchy of such symmetry breaking. This hypothesis was called - the hypothesis of horizontal hierarchy (HHH)[14–16].

The model was based on the gauge $SU(3)_H$ flavor symmetry, which was additional to the symmetry of the Standard model. It means that there exist 8 heavy horizontal gauge bosons and there are three multiplets of heavy Higgs fields $\xi_{ij}^{(n)}$ (i, j - family indexes, $n = 1, 2, 3$) in nontrivial (sextet or triplet) representations of $SU(3)_H$. These heavy Higgs bosons were singlets relative to electroweak symmetry and don't have Yukawa couplings with ordinary light fermions. They had direct coupling to heavy fermions. The latter were singlets relative to electroweak symmetry. Ordinary Higgs ϕ of the Standard model was singlet relative to $SU(3)_H$. It coupled left-handed light fermions f_L^i to their heavy right-handed partners F_R^i , which were coupled by heavy Higgses ξ_{ij} with heavy left handed states F_L^i . Heavy left-handed states F_L^j were coupled to right handed light states f_R^j by a singlet scalar Higgs field η , which was singlet both relative to $SU(3)_H$ and electroweak group of symmetry. The described succession of transitions realized Dirac see-saw mechanism, which reproduced the mass matrix m_{ij} of ordinary light quarks and charged leptons f due to mixing with their heavy partners F . It fixed the ratio of vacuum expectation values of heavy Higgs fields, leaving their absolute value as the only main free parameter, which was determined from analysis of physical, astrophysical and cosmological consequences.

The $SU(3)_H$ flavor symmetry was assumed to be chiral to eliminate the flavor symmetric mass term. The condition of absence of anomalies implied heavy partners of light neutrinos, and the latter acquired mass by Majorana see-saw mechanism. The natural absence in the heavy Higgs potentials of triple couplings, which did not appear as radiative effects of any other (gauge or Yukawa) interaction, supported additional global $U(1)$ symmetry, which could be associated with Peccei-Quinn symmetry and whose breaking resulted in the Nambu-Goldstone scalar field, which shared the properties of axion, Majoron and singlet familon.

Horizontal unification The model provided complete test (in which its simplest implementation was already ruled out) in a combination of laboratory tests and analysis of cosmological and astrophysical effects. The latter included the study of the effect of radiation of axions on the processes of stellar evolution, the study of the impact of the effects of primordial axion fields and massive unstable neutrino on the dynamics of formation of the large-scale structure of the Universe, as well as analysis of the mechanisms of inflation and baryosynthesis based on the physics of the hidden sector of the model.

The model resulted in physically self-consistent inflationary scenarios with dark matter in the baryon-asymmetric Universe. In these scenarios, all steps of the cosmological evolution corresponded quantitatively to the parameters of particle theory. The physics of the inflaton corresponded to the Dirac see-saw mechanism of generation of the mass of the quarks and charged leptons, leptogenesis of baryon asymmetry was based on the physics of Majorana neutrino masses. The parameters of axion CDM, as well as the masses and lifetimes of neutrinos corresponded to the hierarchy of breaking of the $SU(3)_H$ symmetry of families.

The experience gained in the development of this model encourages us to elaborate similar programme for the case of vector-like SU(3)_F family symmetry.

13.3 Horizontal hierarchy in vector-like model

In the approach of vector-like and universal SU(3)_F gauge family symmetry [6,7], all the Standard Model left handed and right handed quarks and leptons transform as the fundamental triplet representation of the SU(3)_F family symmetry. This is the basic starting difference in comparison to the chiral one of Refs. [1,2,8,9], which also defines the different hidden sectors, scalar fields and heavy fermions in order to break symmetries and generate masses for quarks and leptons, as well as the different possible cosmology consequences.

Right handed neutrinos in this approach of vector-like gauge SU(3)_F family symmetry are introduced to cancel anomalies. The fermion content assume a new set of vector - like quarks and leptons U, D, E and N singlets under the SU(3)_F × SU(2)_L symmetry.

SU(3)_F family symmetry is broken spontaneously in two stages by heavy SM singlet scalars $\eta_i^{(n)}$ (i - family index, n = 2, 3) in the fundamental representation of SU(3)_F, generating 5 extremely heavy boson masses ($\gtrsim 100$ TeV's) and 3 almost degenerate boson masses of few TeV's. The "Electroweak Symmetry Breaking" (EWSB) is achieved by the Higgs fields Φ_i^u and Φ_i^d , which transform simultaneously as triplets under SU(3)_F and as the ϕ and $\tilde{\phi} = i\sigma_2 \phi^*$ Higgs doublets under the SM, respectively.

The gauge symmetry $G \equiv SU(3)_F \times G_{SM}$, the fermion content, and the transformation of the scalar fields, all together, avoid Yukawa couplings between SM fermions. The tree level allowed Dirac Yukawa couplings involve terms between the SM fermions $\psi_{SM,(L,R)}$ and the corresponding vector-like fermion F (F=U, D, E and N): $h_F \bar{\psi}_{SM,L} \Phi^{u,d} F_R + h^{(n)} \bar{\psi}_{SM,R} \eta^{(n)} F_L + M_F \bar{F}_L F_R + h.c.$, which yield tree level Dirac See-saw mass matrices for quarks and leptons, including neutrinos, with two massless eigenvalues. Therefore, in this scenario ordinary heavy fermions, top and bottom quarks and tau lepton, become massive at tree level, while light fermions, including light neutrinos obtain masses from radiative corrections mediated by the massive gauge bosons of the SU(3)_F family symmetry.

Neutrinos may also obtain left-handed and right-handed Majorana masses both from tree level and radiative corrections.

13.4 Towards cosmology of vector-like SU(3)_F family symmetry

Here we formulate the open questions for cosmological impact of the model of vector-like SU(3)_F family symmetry. We can stipulate the following cosmologically interesting aspects:

- Is there a candidate for inflaton?
- Which new particles are stable or metastable in vector-like SU(3)_F model
- Are there SU(3)_F instantons or sphalerons?

- What kind of phase transitions can take place in the early Universe with Family symmetry breaking
- Can there be a new mechanism of baryosynthesis? Due to Majorana mass term - there can be leptogenesis with successive redistribution of lepton excess to baryon and lepton excess due to electroweak B and L nonconservation
- Is there additional global symmetry and if, yes, what kind of Nambu-Goldstone (pseudo Nambu Goldstone) solutions can exist?

This list can be modified and extended in the course of our studies.

13.5 Conclusion

Here we have formulated the programme of our joint studies during Albino's sabbatical year in the APC, Paris, France. We hope to present their first results at the coming XX Bled Workshop.

Acknowledgements

AHG acknowledge partial support by the "Instituto Politécnico Nacional", (Grants from EDI and COFAA) and "Sistema Nacional de Investigadores" (SNI) in Mexico. The work by M.K.was performed within the framework of the Center FRPP supported by MEPhI Academic Excellence Project (contract 02.03.21.0005, 27.08.2013). The part on initial cosmological conditions was supported by the Ministry of Education and Science of Russian Federation, project 3.472.2014/K and on the forms of dark matter by grant RFBR 14-22-03048.

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