SUSY SM AND SUSY GUT AXIONS AS DARK MATTER

Jizong Lu [1]
Institut für Physik, Universität Dortmund, D-44221 Dortmund, Germany
and
Department of Physics, Shanghai Teachers University, Shanghai 200234, P.R. China [2]

Abstract

Recently the interest in the axion has enhanced since it is a good candidate for cold dark matter. We discuss invisible axions, which agree with conditions as a cold dark matter candidate, in both local SUSY SU(3)⊗SU(2)⊗U(1) and local SUSY GUT SO(10) models. Several possible ways of searching for axions are discussed too.

---

[1] DAAD/K.C. Wong Fellow; e-mail address: luj@hall.physik.uni-dortmund.de

[2] permanent address

1. Introduction

There are several obvious evidences indicating the existence of nonluminous matter in the Universe, galaxies and holes, furthermore, the bulk of it must be non-baryonic.[3] The interest in axions as a possible dark matter candidate has been enhanced recently, although there are many others. There are two reasons. First, the COBE observations of structure in the microwave background radiation favor cold dark matter cosmologies [1]. The axion is one of prime candidates for cold dark matter. Second, some interesting experiments to search for the axion have a realistic chance of finding these elusive particles [2].

The axion was first proposed as an elegant solution to the strong CP violation problem in QCD [3]. It was realised soon that axions could have an important role to play as a dark matter candidate since they acquire a small mass at the QCD phase transition.

In this talk I would like to present our results of axions in both SUSY SM and SUSY GUT models, in which the strong CP violation was eliminated via the DFSZ mechanism [4] and the $\mathrm{U_{PQ}}(1)$ breaking scale f_a is close to the geometric hierarchy mass scale $M_R \equiv \sqrt{M_U M_W} \approx 10^{11}{\sim}10^{12}$GeV. Thus, the axion mass in the models is around 10^{-5}eV and the low energy coupling to normal matter is suppressed by $1/f_a$. These make it to be a good candidate for cold dark matter. There are only two prime cold dark matter candidates: axions and neutralinos [5], so to discuss axions as cold dark matter in some SUSY models is still significant.

2. The Axion in a SUSY SU(3)⊗SU(2)⊗U(1) Model

There are several motivations to discuss axions in SUSY models. Say, there is so called automaticity of the PQ symmetry. Two Higgs doublets are needed to implement a $\mathrm{U_{PQ}}(1)$ symmetry in original axion models. On the other hand, minimal SUSY models also require two SU(2) doublet Higgs superfields H and H'. Because if there were only one Higgs superfield, the theory could not be anomaly free. SUSY might give PQ symmetry an automaticity. Thus, the interest in SUSY axion models has recently soared [6].

At first, I would like to introduce a SUSY $\mathrm{SU_c}(3) \otimes \mathrm{SU}(2) \otimes \mathrm{U}(1)$ axion model, in which the gauge interaction is the same as those in the Standard Model (SM). The superpotential f is

$$f = aQU^cH + bQD^c\bar{H} + cLE^c\bar{H} + dH\bar{H}S + \delta SSS, \tag{1}$$

where H, $\bar{H}$, L and Q are SU(2) doublets; D^c, U^c and E^c are singlets; Q, D^c and U^c are SU(3) triplets and S is the singlet for both SU(3) and SU(2). The VEV's are $< S >= v, < H >= v_1, < \bar{H} >= v_2$ with all others vanishing. We can set $v_1 \sim v_2 \ll v$. The potential ν is

$$\nu = |\frac{\partial f}{\partial z_i}|^2 + |g_\alpha z_i^* T_\alpha z_i + \xi_\alpha|^2, \tag{2}$$

where z_i denote all fields, g_α is the group coupling constant and T_α is the group generator. ξ_α is an arbitrary parameter which is non-zero only for $\mathrm{U_Y}(1)$ group and to break the supersymmetry. There is an additional $\mathrm{U_A}(1)$ symmetry in the potential ν. Axions will be occur in its breaking.

---

[3] for example, see lectures: K. Olive, *Why Do We Need Non-Baryonic Dark Matter* and G. Jungman, *Particle Dark Matter* in this proceedings.

If replace the complex scarlar fields $H, \bar{H}$ and S by their phase fields respectively: $H_0 \to e^{iv_1\eta_1}$, $\bar{H}_0 \to e^{iv_2\eta_2}$, $S \to e^{iv\eta_s}$, then we have the axion current:

$$j_{\mu a} \sim \frac{2}{3}(v_1\partial_\mu\eta_1 + v_2\partial_\mu\eta_2 + v\partial_\mu\eta_s) = \frac{2}{3}\sqrt{v_1^2 + v_2^2 + v^2}\partial_\mu\eta_a, \tag{3}$$

where $\eta_a = (\sqrt{v_1^2 + v_2^2 + v^2}\,)^{-1}(v_1\eta_1 + v_2\eta_2 + v\eta_s)$ is the axion field and $f_a = \frac{2}{3}\sqrt{v_1^2 + v_2^2 + v^2} \sim \frac{2}{3}v$. The axion mass can be estimated by the standard current algebra method.

$$m_a^2 = \frac{m_{a_0}^2}{\sqrt{2}f_a^2 G_W} = \frac{9m_{a_0}^2}{4\sqrt{2}v^2 G_W}, \tag{4}$$

where $m_{a_0} \sim 50\text{keV}$. Combining this model with $N = 1$ supergravity and introducing SUSY breaking in the second term of the potential ν, the gravitino acquires a mass:

$$\frac{m_{3/2}}{M} = \frac{9}{8\sqrt{2}}K^2\frac{m_{a_0}^2}{m_e^2 G_W}. \tag{5}$$

It is a mass relation among gravitinos, axions and other fermions. The axion mass expression can be obtained from it:

$$m_a^2 = \frac{9}{8\sqrt{2}}K^2\frac{m_{A_0}^2}{G_W}\frac{M}{m_{3/2}} \approx 1.6 \times 10^{-23}\frac{M}{m_{3/2}}(\text{eV})^2. \tag{6}$$

If setting $f_a = M_R \approx 10^{11} \sim 10^{12}\text{GeV}$, $m_{3/2} \approx 10^3 \sim 10^4\text{GeV}$, and $M = M_P \approx 10^{19}\text{GeV}$, then the axion mass window in our model is as follows:

$$2 \times 10^{-5}\text{eV} < m_a < 4 \times 10^{-4}\text{eV}, \tag{7}$$

3. Embedding in a Local SUSY GUT SO(10) Model

We can also similarly discuss the axion model in a local SUSY GUT SO(10) model. The symmtry breaking chain is

$$\text{SO}(10)\otimes\text{U}_{\text{PQ}}(1) \xrightarrow{M_u} \text{SU}_c(4)\otimes\text{SU}_\text{R}(2)\otimes\text{SU}_\text{L}(2)\otimes\text{U}_{\text{PQ}}(1) \xrightarrow{M_R} \text{SU}_c(3)\otimes\text{SU}(2)\otimes\text{U}(1),$$

where $M_u \sim 10^{16}\text{GeV}$ and $M_R \sim 10^{12}\text{GeV}$. $\text{U}_{\text{PQ}}(1)$ is broken at M_R.

In this model, the superfields are

$S(54, 0)$ $H^\beta(10, -2)$ $G^\beta(10, 2)$ χ^α
$U(1, 0)$ $\psi^\beta(16, 1)$ $\bar{\psi}^\beta(16, -1)$ $\beta = 1, 2$

where $a = 1, 2, 3$ is the family index. The first number in the paenthese is the dimension of representation and the second one is the quantum number of $U_{PQ}(1)$.

The superpotential is

$$f = \frac{1}{2}\mu\text{Tr}(SS) + \frac{1}{3}h\text{Tr}(SSS) + \sum_\beta cU(\bar{\psi}^\beta\psi^\beta - M_R^2) - \sum_\beta(aH^\beta SG^\beta + \frac{3}{2}aVH^\beta G^\beta)$$

$$+\sum_\beta b(\psi^1\psi^1 H^\beta + \bar{\psi}^1\bar{\psi}^1 G^\beta - \psi^2\psi^2 H^\beta - \bar{\psi}^2\bar{\psi}^2 G^\beta) + \sum_{a,b,\beta} h_{ab}^\beta H_i^\beta \chi_a^T \Gamma^i \chi_b. \tag{8}$$

The potential is

$$\nu = f_i^2 + \frac{1}{2} D^\alpha D^\alpha \tag{9}$$

where $f_i = \partial f / \partial z_i$, z_i stands for all fields. The VEV's are

$$< S >= S_0 = v(1,1,1,1,1,1,-\frac{3}{2},-\frac{3}{2},-\frac{3}{2},-\frac{3}{2}), v = \frac{2\mu}{h};$$
$$< \psi_{16}^\beta >=< \bar{\psi}_{16}^\beta >= X_0 = M_R/\sqrt{2}; \qquad < H^\beta >=< G^\beta >= U = 0. \tag{10}$$

After coupling it with $N = 1$ supergravity, the VEV's are determined by

$$f_i + \frac{1}{2} K^2 z_i^* f = 0. \tag{11}$$

Thus eq. (10) becomes

$$< S >= S_0 + S_1, S_1 = (0,0,0,0,0,0,+\varepsilon,+\varepsilon,-\varepsilon,-\varepsilon), \qquad \varepsilon = -\frac{5}{8} K^2 h v^3;$$
$$< \psi_{16}^\beta >=< \bar{\psi}_{16}^\beta >= X_0 + \varepsilon^2; < H_0^\beta >=< G_0^\beta >= P_+; < H_3^\beta >=< G_3^\beta >= iP_-; < U >= -\frac{\varepsilon}{c}, \tag{12}$$

where $P_\pm = (5Khv^2/2\sqrt{2})[(1/$[illegible]$)(1/2 \pm 1/h)]^{1/2}$. Choosing these coefficients appropriately, the expecting low-energy behaviour can be obtained.

4. Summary and Discussion

In both SUSY SM and SUSY GUT models, we set the $U_{PQ}(1)$ breaking scale f_a at $M_R = 10^{12}$GeV. The axion mass is around a few $\times 10^{-5}$eV. It has been shown such axions would provide closure density, and would be the dark matter. Our axion mass window eq. (7) agrees with most constraints from cosmology and astrophysics

The axion interacts with the photon in analogy to π^0. This interaction allows the axion decay to 2γ. If one photon is emitted along the direction of the axion moving and the other in opposite direction, there is a difference in the photon energy between these two directions. This provides an opportunity of searching for axions. Several optical experiments have been proposed and some of them are on the way [2]. Because $g_{a\gamma\gamma}$ is strongly sensitive to the PQ charge assignments. In our SUSY SM axion model, the PQ charges are the same as those in DFSZ models. The results of such experiments will probably distinguish different models.

The source of cosmic axions is cosmic strings. From the radiation of cosmic strings, one can calculate and the axion density and its fluctuations. It is well known that large amplitude density fluctuations produced on scales of the horizon at the QCD epoch will cause gravitational bound "miniclusters". If the axion miniclusters exist, they can be detected by femtolensing (or picolensing) because they naturally meet all three conditions of detecting [7]. This will probably provide another way to catch these elusive particles.

Acknowledgements

The author would like to thank DAAD - K.C. Wong Forschungsstipendien for the financial support and Prof. Dr. E.A. Paschos for hospitality at the Universität Dortmund, where this talk was finally completed.

References

[1] G.F. Smoot *et al., Astrophys. J.* **396** (1992) 3; S. Hancock *et al., Nature*(London) **367** (1994) 333

[2] K. van Bibber *et al.,* Preprint UCRL-JC-118357 (1994); S.L. Cheng, C.Q. Geng and W.-T. Ni, Preprint hep-ph 9506295 (1995); P.V. Vorobyov and I.V. Kolokolov, Preprint astro-ph 9501042 (1995)

[3] R. Peccei and H. Quinn, *Phys. Rev. Lett.* **38** (1977) 1440; *Phys. Rev.* **D16** (1977) 1791; S. Weinberg, *Phys. Rev. Lett.* **40** (1978) 223; F. Wilczek, *Phys. Rev. Lett.* **40** (1978) 279

[4] M. Dine, W. Fishler and M. Srednicki, *Phys. Lett.* **104B** (1981) 199; A. P. Zhitnitskii, *Sov. J. Nucl. Phys.* **31** (1980) 260

[5] J. Ellis and R. Flores, *Phys. Lett.* **263B** (1991) 259; *Nucl. Phys.* **B400** (1993) 25; *Phys. Lett.* **300B** (1993) 175.

[6] K.S. Babi, K. Choi, J.C. Pati and X. Zhang, *Phys. Lett.* **333B** (1994) 364; J. Bagger, E. Poppitz and L. Randall, *Nucl. Phys.* **B426** (1994) 3; E.A. Dudas, *Phys. Rev.* **D49** (1994) 1109

[7] E.W. Kolb and I.I. Tkachev, *Phys. Rev. Lett.* **71** (1993) 3051; Preprint astro-ph 9510043 (1995)

AXIONS DE SUSY SM ET DE SUSY GUT COMME CANDIDAT À LA MATIÈRE NOIRE