A Light Pseudoscalar as a Dark Matter Candidate

R. Armillis, C. Corianò, M. Guzzi, A. Mariano and S. Morelli [1] [2]

[1]Dipartimento di Fisica, Università del Salento, Italy

[2]Istituto Nazionale di Fisica Nucleare sez. di Lecce, Italy

Particle physics candidates for dark matter abound, the most popular being the lightest neutralino of supersymmetric models such as the Minimal Supersymmetic Standard Model (MSSM) and its extensions. On the other hand, non-supersymmetric models also have their own dark matter candidate, the most popular one being the axion. Introduced by Peccei and Quinn [1] long ago to solve the strong CP problem, the axion has required an extra global $U(1)$ symmetry, attached to the fields of the Standard Model (SM).

Its inclusion in a supersymmetric lagrangean has also always required the introduction of an extra global symmetry, together with a supersymmetric partner (the axino). To bring both components (the axion and the neutralino) under the spell of the gauge principle requires, quite likely, a gauging of the axionic symmetries.

The study of axionic symmetries and of their gauging is an important aspect of string theory at lower energy, being connected with the presence, in these effective models, of several moduli fields, deprived of a potential and derived from geometrical compactifications. These lagrangeans find a consistent formulation in special versions of supergravity theories [2] which are supposed to play a role in the study of the dynamics of the early universe.

The attempt to match these descriptions with effective models (with or without supersymmetry and gravity) based on ordinary quantum field theory and supersymmetry (in flat space) is pursued in several works [3,4], where the role of the anomalous interactions and of light pseudoscalars is investigated under the tenets of gauge invariance and unitarity [5]. In general, these effective field theories are characterized by the presence of higher dimensional operators to correct for the exposed (axial) anomaly (in the form of Wess-Zumino terms with Stückelberg axions) [3]. Their gauge structure, in fact, requires at least one extra anomalous $U(1)$ interaction.

The presence of gauge couplings and of a mass for this axion not related by the same suppression scale (f_a) - which is of the order of 10^{10} GeV for a traditional (ungauged) axion - makes this new axion a very attractive dark matter candidate.

However, building axion models with gauged axionic symmetries is rather challenging from the field theory point of view since it requires a grasp of the unusual features of the chiral anomaly, from the organization of the effective action(s) to the presence of anomaly poles that challenge the consistency of the S-matrix in some of their scattering amplitudes [6].

One of the realizations of field theories which contain axion-like particles in their spectrum is the Minimal Low-Scale Orientifold Model (MLSOM) [7], based on a construction involving charge assignments obtained from intersecting branes. These models introduce one Stückelberg axion for each anomalous $U(1)$ present in the gauge structure. In [7] it is shown that the physical spectrum of the MLSOM contains always one physical axion, independently of the number of anomalous U(1)'s.

Supersymmetric extensions of these class of models have been discussed rather recently [8], using a superpotential which is the one typical of the UMSSM [9]. Respect to the MSSM, the UMSSM contains an extra singlet superfield and an extra U(1) gauge symmetry, which is anomaly free. In the UMSSM-A model of [8], which is the theory proposed as a possible supersymmetric extension of the MLSOM, this symmetry has been left anomalous, and the bosonic mechanism of cancellation of these anomalies, which is enforced via the inclusion of Wess-Zumino (counter)terms, has been generalized. These models contain a combined Higgs-Stückelberg mechanism for the generation of the mass of the anomalous gauge bosons.

A physical axion state (the axi-Higgs) appears quite naturally, together with its supersymmetric partner, the axino. This second state becomes a component of the fermionic neutralinos, after diagonalization of the mass matrix of the neutral fermion sector.

Compared to other constructions, in which the axion disappeares from the physical spectrum being just a goldstone mode, in the UMSSM-A the presence of the extra singlet superfield allows a physical projection of the Stückelberg axion of the model on the axi-Higgs (χ). Therefore this physical state inherits direct axion-like couplings (such as $\chi F\tilde{F}$) to the gauge fields, becoming a gauged supersymmetric axion [10].

The particle is massless in the absence of Peccei-Quinn-breaking potentials, in which the axion appears as a phase, while the instanton vacuum can naturally lift its mass up to 10^{-4} eV as in the Peccei Quinn (invisible axion) case.

In the non-supersymmetric version of these theories, i.e. in the MLSOM, one of the special features of these theories is the presence of anomalous trilinear gauge interactions, which are totally absent in the Standard Model (SM) due to anomaly cancellation [11]. We just recall that in the SM these interactions are suppressed and appear only away from the chiral limit in AVV diagrams (for instance in $Z\gamma\gamma$ vertices).

The search for light (gauged) pseudoscalars is for sure a challenge for the experimental acvitity at the LHC [12], requiring precise evaluation of the QCD background. However, while the detection of anomalous extra Z prime which modify the neutral current sector of these theories remains difficult, the identification of a light pseudoscalar (in the mass range of 1 to 10 GeV), which is their second signature, is more favoured.

REFERENCES

1. R.D. Peccei and H.R. Quinn, Phys. Rev. D16 (1977) 1791.
2. J. De Rydt et al., Class. Quant. Grav. 24 (2007) 5201, 0705.4216.
3. C. Corianò, N. Irges and S. Morelli, JHEP 07 (2007) 008, hep-ph/0701010.
4. C. Corianò, N. Irges and S. Morelli, Nucl. Phys. B789 (2008) 133, hep-ph/0703127.
5. R. Armillis et al., JHEP 10 (2008) 034, 0808.1882.
6. C. Corianò, M. Guzzi and S. Morelli, Eur. Phys. J. C55 (2008) 629, 0801.2949.
7. C. Corianò, N. Irges and E. Kiritsis, Nucl. Phys. B746 (2006) 77, hep-ph/0510332.
8. C. Corianò et al., (2008), 0811.3675.
9. M. Cvetic et al., Phys. Rev. D56 (1997) 2861, hep-ph/9703317.
10. C. Corianò et al., (2008), 0811.0117.
11. R. Armillis, C. Corianò and M. Guzzi, JHEP 05 (2008) 015, 0711.3424.
12. R. Armillis et al., (2008), 0809.3772.