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Einstein–Maxwell-axion theory: dyon solution with regular electric field

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Abstract In the framework of the Einstein–Maxwell-axion theory we consider static spherically symmetric solutions which describe a magnetic monopole in the axionic environment. These solutions are interpreted as the solutions for an axionic dyon, the electric charge of which is composite, i.e. in addition to the standard central electric charge it includes an effective electric charge induced by the axion–photon coupling. We focus on the analysis of those solutions which are characterized by the electric field regular at the center. Special attention is paid to the solutions with the electric field that is vanishing at the center, and that has the Coulombian asymptote, and thus displays an extremum at some distant sphere. Constraints on the electric and effective scalar charges of such an object are discussed.

1 Introduction

In 1987 Wilczek has formulated the idea that for a distant observer the magnetic monopole in an axionic environment looks like a dyon with a magnetic and effective electric charge [1]. This idea was based on the prediction of the axion electrodynamics where the interaction between the radial magnetic field attributed to the monopole and the surrounding pseudoscalar (axion) field produces the radial electric field without real electric charge at the center. That is why it is said that Wilczek in 1987 presented the first example of the so-called axionic dyon. The axion electrodynamics on which this result was based have been established and developed in the decade 1977–1987, being inspired by the theoretical discovery of Peccei and Quinn of the CP-invariance conservation [2] and by discussions about a new light pseudo-Goldstone boson introduced by Weinberg [3] and Wilczek [4]. The model of the coupling of the pseudoscalar and electromagnetic fields was formulated in a covariant form by Ni in [5]; the axion electrodynamics written in the 3-dimensional form was used by many authors (see, e.g., the work of Sikivie [6]). Since the axions are considered to be candidates to the dark matter particles [7–15] the physics of axions had become one of the key elements of numerous applications to cosmology and astrophysics. These applications take into consideration various models of interaction of gravitational, electromagnetic, scalar and pseudoscalar fields which are nowadays called the Einstein–Maxwell-axion and Einstein–Maxwell-axion–dilaton models (see, e.g., [16–18]). Also, these applications focus the attention on the models which belong to the class of theories associated with extended axion electrodynamics [19–26].

In 1991 Lee and Weinberg [27] studied spherically symmetric solutions for static black holes with a massless axion-like scalar field; in fact it was a realization of the Wilczek idea in the framework of the Einstein–Maxwell-axion theory. Lee and Weinberg have obtained self-consistent master equations for the axion field and metric coefficients, analyzed the asymptotic properties of the solutions and studied the analytic and numeric solutions for the cases of large and small values of the constant of the axion–photon coupling. If we omit the initial electric charge at the center of the object described in [27] we find the solution for the axionic dyon, which was obtained in the framework of the Einstein–Maxwell-axion model and was predicted in [1] using the simple Maxwell-axion model. In this sense it can be said that in [1,27] the authors presented the first (static) example of the so-called longitudinal magneto-electric cluster in which the magnetic and axionically induced electric fields are parallel to one another. Later the solutions describing the Longitudinal Clusters were found in the systems with the pp-wave symmetry [28] and in the context of the search for fingerprints of relic axions in the terrestrial magnetosphere [29].

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