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Some new results on charged compact boson stars

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ABSTRACT

In this work we present some new results obtained in a study of the phase diagram of charged compact boson stars in a theory involving a complex scalar field with a conical potential coupled to a U(1) gauge field and gravity. We here obtain new bifurcation points in this model. We present a detailed discussion of the various regions of the phase diagram with respect to the bifurcation points. The theory is seen to contain rich physics in a particular domain of the phase diagram.

In this work we study the phase diagram of charged compact boson stars in a theory involving a complex scalar field with a conical potential coupled to a U(1) gauge field and gravity [1,2]. A study of the phase diagram of the theory yields new bifurcation points (in addition to the first one obtained earlier, cf. Refs. [1,2]), which implies rich physics in the phase diagram of the theory. In particular, we present a detailed discussion of the various regions in the phase diagram with respect to the bifurcation points.

Let us recall that the boson stars (introduced long ago [3–5]) represent localized self-gravitating solutions studied widely in the literature [6–10,1,2,11–13,17,16,14,15].

In Refs. [16,17], three of us have undertaken studies of boson stars and boson shells in a theory involving a massive complex scalar field coupled to a $U(1)$ gauge field A_μ and gravity in the presence of a cosmological constant Λ. Our present studies extend the work of Refs. [1,2], performed in a theory without a cosmological constant Λ for a complex scalar field with only a conical potential, i.e., the scalar field is considered to be massless. Such a choice is possible for boson stars in a theory with a conical potential, since this potential yields compact boson star solutions with sharp boundaries, where the scalar field vanishes. This is in contrast to the case of non-compact boson stars, where the mass of the scalar field is a basic ingredient for the asymptotic exponential fall-off of the solutions.

We construct the boson star solutions of this theory numerically. Our numerical method is based on the Newton–Raphson scheme with an adaptive stepsize Runge–Kutta method of order 4. We have calibrated our numerical techniques by reproducing the work of Refs. [1,2] and [14–17].

We consider the theory defined by the following action (with $V(|\Phi|) := \lambda|\Phi|$, where λ is a constant parameter):

$$
\begin{aligned}
S &= \int \left[\frac{R}{16\pi G} + \mathcal{L}_M \right] \sqrt{-g}\, d^4 x\,, \\
\mathcal{L}_M &= -\frac{1}{4} F^{\mu\nu} F_{\mu\nu} - \left(D_\mu \Phi\right)^* \left(D^\mu \Phi\right) - V(|\Phi|)\,, \\
D_\mu \Phi &= (\partial_\mu \Phi + ieA_\mu \Phi)\ , \\
F_{\mu\nu} &= (\partial_\mu A_\nu - \partial_\nu A_\mu). \qquad (1)
\end{aligned}
$$

Here R is the Ricci curvature scalar, G is Newton's gravitational constant. Also, $g = det(g_{\mu\nu})$, where $g_{\mu\nu}$ is the metric tensor, and the asterisk in the above equation denotes complex conjugation. Using the variational principle, the equations of motion are obtained as:

$$
\begin{aligned}
G_{\mu\nu} \equiv R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R &= 8\pi G T_{\mu\nu}\,, \\
\partial_\mu \left(\sqrt{-g} F^{\mu\nu}\right) &= -ie\sqrt{-g}[\Phi^*(D^\nu \Phi) - \Phi(D^\nu \Phi)^*]\,, \\
D_\mu \left(\sqrt{-g} D^\mu \Phi\right) &= \frac{\lambda}{2} \sqrt{-g}\, \frac{\Phi}{|\Phi|}\,,
\end{aligned}
$$

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