Eur. Phys. J. C (2019) 79:496
https://doi.org/10.1140/epjc/s10052-019-7006-y

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

Phase diagrams of charged compact boson stars

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Received: 26 December 2018 / Accepted: 2 June 2019 / Published online: 12 June 2019

Abstract Compact boson stars, whose scalar field vanishes identically in the exterior region, arise in a theory involving a *massless* complex scalar field with a conical potential, when coupled to gravity. Their charged compact generalizations, obtained in the presence of a U(1) gauge field, exhibit further interesting features. On the one hand, charged compact boson shells can arise, whose scalar field vanishes also in the central region, while on the other hand, the domain of existence of charged compact boson stars exhibits bifurcation points. First 2D phase diagrams have been studied before. Here we extend these earlier studies to a larger range of the variables and study additional phase diagrams. We then extend these studies to obtain 3D phase diagrams and present these with a detailed discussion of their various regions with respect to the bifurcation points and argue, that there is an infinite series of such bifurcation points. Thus the theory is seen to contain rich physics in a particular domain of the phase diagrams. We also discuss the dependence of the fields on the dimensionless radial coordinate for some representative points of the phase trajectories in the phase diagrams of the theory.

1 Introduction

Boson stars represent localized solutions of scalar fields coupled to gravity (see the reviews [1–5]). In their original form, they are based on a complex scalar field with a mass term only [6–8], while later work has included self-interactions of the scalar field, allowing for much higher masses of the resulting boson stars [9,10].

Since being first conceived half a century ago, boson stars have received tremendous interest. Much of this interest resides in their potential astrophysical applications. These range from being promising dark matter candidates all the way to representing highly compact supermassive objects in galactic centers [1–5]. Among the many applications accretion disks around boson stars have been considered [11,12] or the gravitational-wave signatures of boson stars and binary systems of boson stars have been studied [13,14]. In addition, boson stars have found applications based on the AdS/CFT conjecture [15].

However, boson stars are also interesting from a more theoretical point of view. On the one hand, they allow a study of numerous features of more complicated systems, and thus represent a nice model to learn and analyze. On the other hand, they contain the freedom to allow for new fascinating properties, not encountered before – at least not under similar circumstances. One of the most impressive recent examples in this context represents the discovery of hairy black holes based on boson stars [16,17]. Another recent surprise was the realization that rotating boson stars allow for static orbits [18].

When considering the properties of boson stars, first of all their mass, their particle number and their size, are of interest. The particle number of boson stars arises from the U(1) symmetry of the underlying theory, which gives rise to a conserved current and thus an associated charge. When the U(1) symmetry is made a local symmetry, charged boson stars arise [19–24]. While their particle number is proportional to their charge, their basic features seem to only straightforwardly generalize those of their uncharged brethren. This changes fundamentally, when a different type of scalar field potential is employed, namely a conical potential [25,26].

First of all, a conical potential allows for compact boson star solutions, where *compact* is not meant to describe the physical property of having a large mass residing in an area with a small radius, as typically employed in connection with neutron stars or black holes. Here *compact* is meant

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