PhD **Open Days**

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The versatility of stubbornness: the many faces of Boson Stars

PHD PROGRAM IN PHYSICS

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Introduction

The concept of *stability* is one which is deeply connected with the definition of *existence*: something exists as long as it is stable; while it is unstable, the object under analysis lacks definition - it is neither the initial state nor the end state.

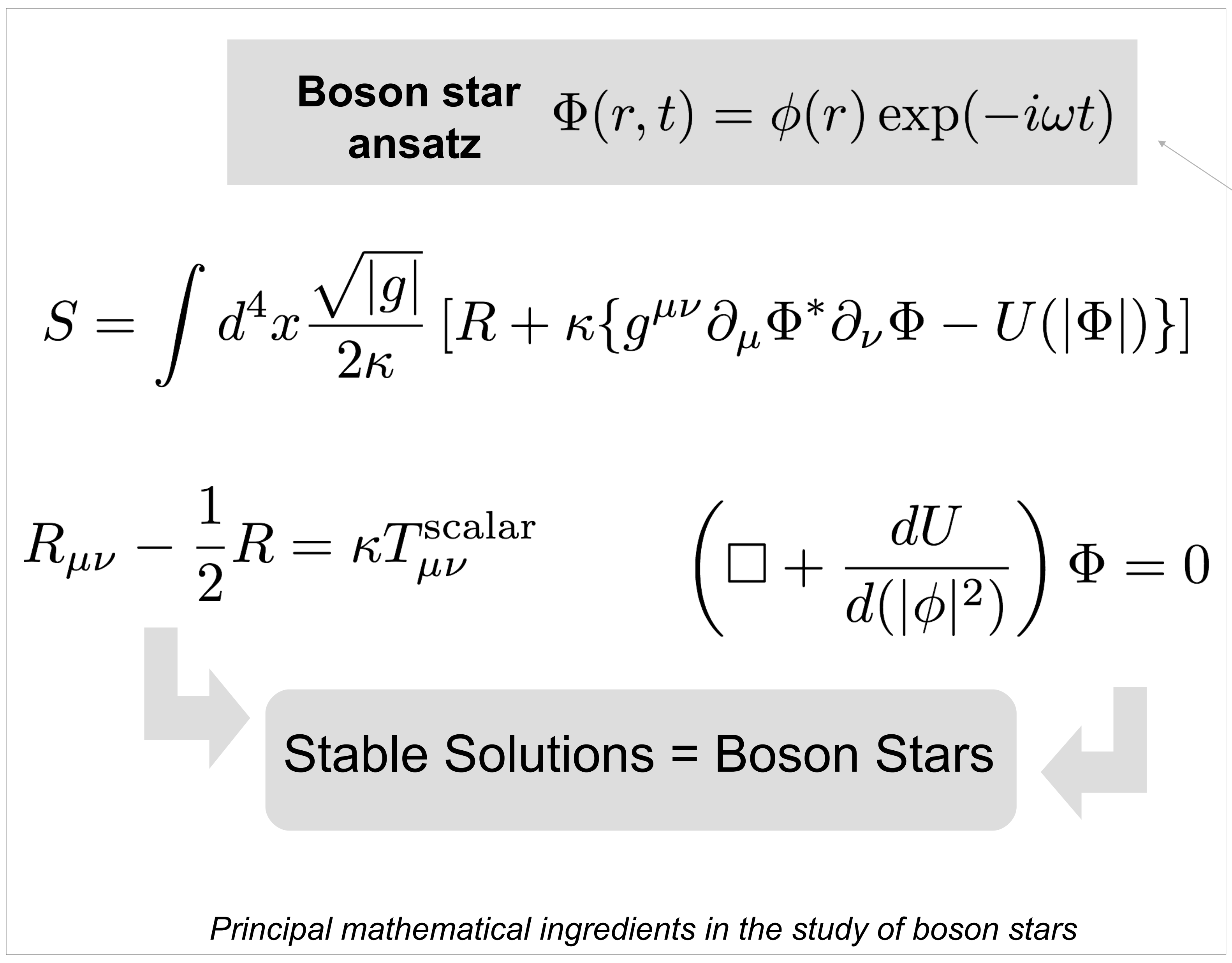
The world we observe exists and we understand it as being stable. Having this idea carved in the back of our minds, it seems natural that whenever one finds, in the midst of some mathematical exploration, an object that displays remarkable stability, one pays close attention to it. Such object may be able to reproduce the behavior of some observed phenomena and, moreover, allow an indirect exploration of more properties of such phenomena by mathematical enquiry. Solitons are the kind of mathematical objects that fit this description.

A **soliton** is a highly stable solution of a PDE that supports wave-like solutions; it is a wave that propagates without changing its form and that is unaffected by collisions with other solitons – it is, indeed, a stubborn wave!

A **boson star** is a special kind of soliton (a Non Topological Soliton (NTS)) that can be found in scalar field theories analysed in curved spacetime [1] (see the picture with a simple sketch). The name given to these NTS is quite suggestive: one is looking at stable solutions of scalar fields that can compete in terms of its characteristic masses and radiuses with the usual stellar objects.

Mathematical Details

Boson stars are **simple objects** that use a minimal set of tools: the classical field theory and general relativity machinery. Using a specific kind of ansatz for a complex scalar field (i.e. there is a global charge associated with the U(1) symmetry) one can obtain absolutely stable solutions for the equations of motion. It is remarkable!



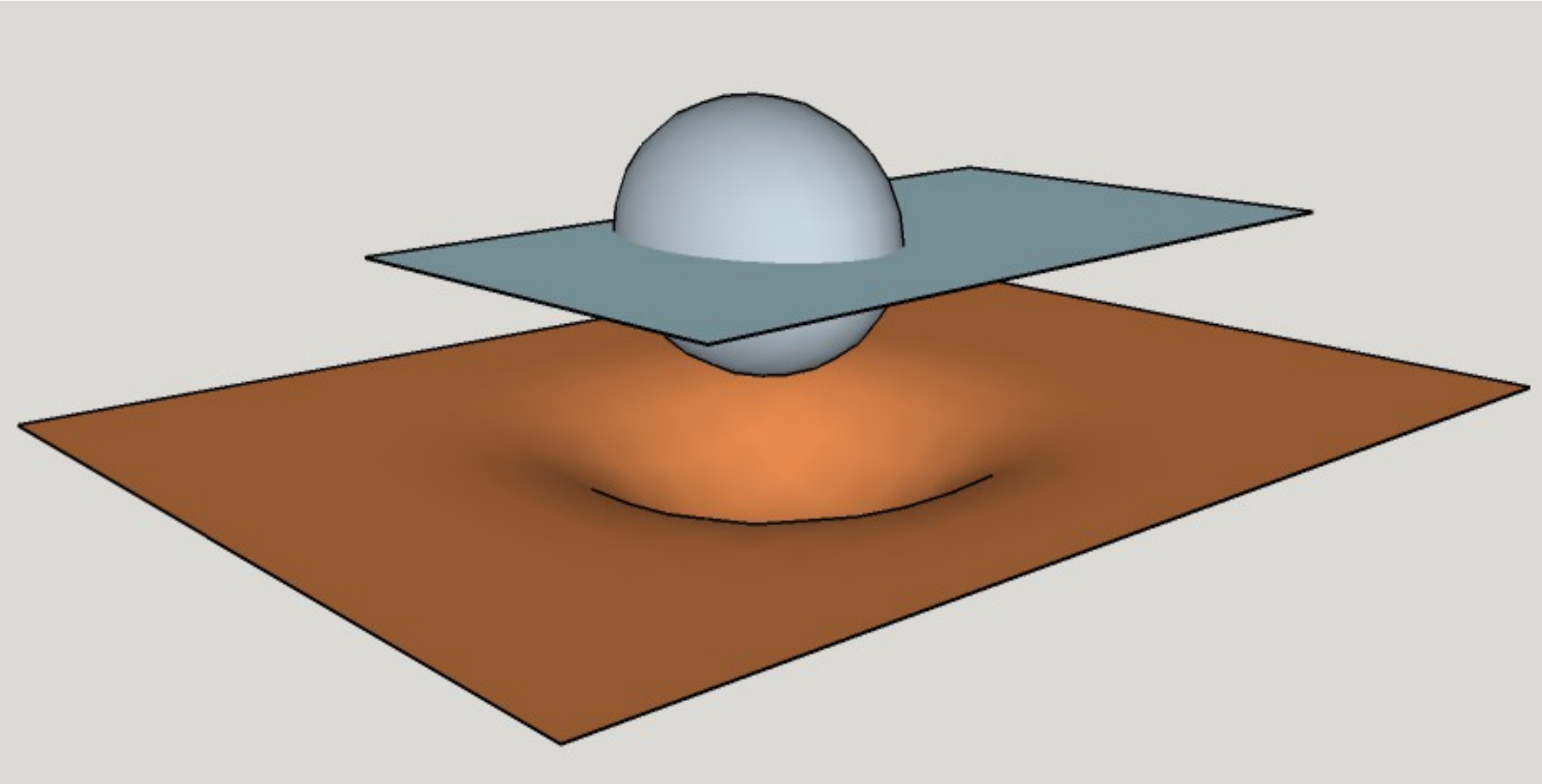
Boson star ansatz $\Phi(r,t) = \phi(r)\exp(-i\omega t)$

$$S = \int d^4x \frac{\sqrt{|g|}}{2\kappa}\left[R + \kappa\{g^{\mu\nu}\partial_\mu\Phi^*\partial_\nu\Phi - U(|\Phi|)\}\right]$$

$$R_{\mu\nu} - \frac{1}{2}R = \kappa T^{\text{scalar}}_{\mu\nu} \qquad \left(\Box + \frac{dU}{d(|\phi|^2)}\right)\Phi = 0$$

Stable Solutions = Boson Stars

Principal mathematical ingredients in the study of boson stars



Schematic representation of a solitonic configuration of a scalar field and its effect on the background spacetime.

Versatility of boson stars

There are many boson star models, each of them being defined by the scalar field potential used in the equations. From all these models it is possible to extract a condition for the **maximum mass of the boson stars**. For the simplest case – a potential of a free particle – the maximum mass is given by $0.633(M^2_{Pl}/m)$ [1]. Other models possess different limits which makes boson stars cover a wide range of the characteristic space – in that sense they are highly versatile objects.

Black hole mimickers, dark matter and so on

Exploring the stability and diversity of boson star solutions, it was possible to propose explanations for some phenomena based on these objects: they are used as **black hole alternatives** and as **dark matter candidates**[2]. Tthey can also play a role as stellar objects on their own, with some observational characteristics being figured out such as the possible emission of **Cherenkov radiation**[3] and the particular gravitational lens effect **due to the lack stellar surface**[4].

Boson stars can even exist in a synergy regime with ordinary matter stars in the so-called **boson-fermion stars**[5].

Spinor fields

Having been recognized much earlier in history as a fundamental building block of Nature, the spinor is not only more complicated to treat mathematically than a scalar but also a much more pervasive manifestation of reality – all the known fundamental matter particles are described by this object.

We want to pursue a study of spinor fields in a classical regime similar to the one presented for boson stars. This means that **we want to study a spinor field minimally coupled to gravity and search for solitonic solutions**. This study will provide us with more insight on the way solitonic structures are formed and will allow us to study what is the influence that the spin has on the stability of a putative spinor soliton.

Spinor ansatz $\Psi = e^{-i\omega t}\begin{pmatrix}\chi(r,\theta,\phi)\\ \psi(r,\theta,\phi)\end{pmatrix}$

$$(i\tilde{\gamma}^\mu[\partial_\mu + \Gamma_\mu] - m)\Psi = 0$$

New ingredients added for the study of spinor fields

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