PhD Open Days

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Gravitational Collapse in Curved Spacetime

Ph. D. in Physics

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Introduction

Motivation

Our Universe has some of the most exotic and fascinating objects: black holes (BH). Although there is very little direct evidence about their existence, they are the most conservative explanation to some phenomena that we observe, such as the motion of stars in the center of our galaxy or the recent detection of gravitational waves.

Although we know a lot about black holes, their formation process is still a mystery due to the complexity and nonlinearity of General Relativity.

Model

In order to get some insight on the formation process of black holes we will use scalar fields to describe the matter present in the Universe. We will also consider that the whole system is spherically symmetric as to simplify the problem. For the dynamics of the field we include a kinetic term and a mass term as the field's potential. We also require these fields to be confined inside the spacetime. This can be done by introducing a negative cosmological constant to our model, i. e. by changing the geometry of the spacetime. This spacetime is known as the Anti-de Sitter (AdS) spacetime. In the appropriate coordinates, the AdS spacetime can be represented as a cylinder, as presented in Figure 1.

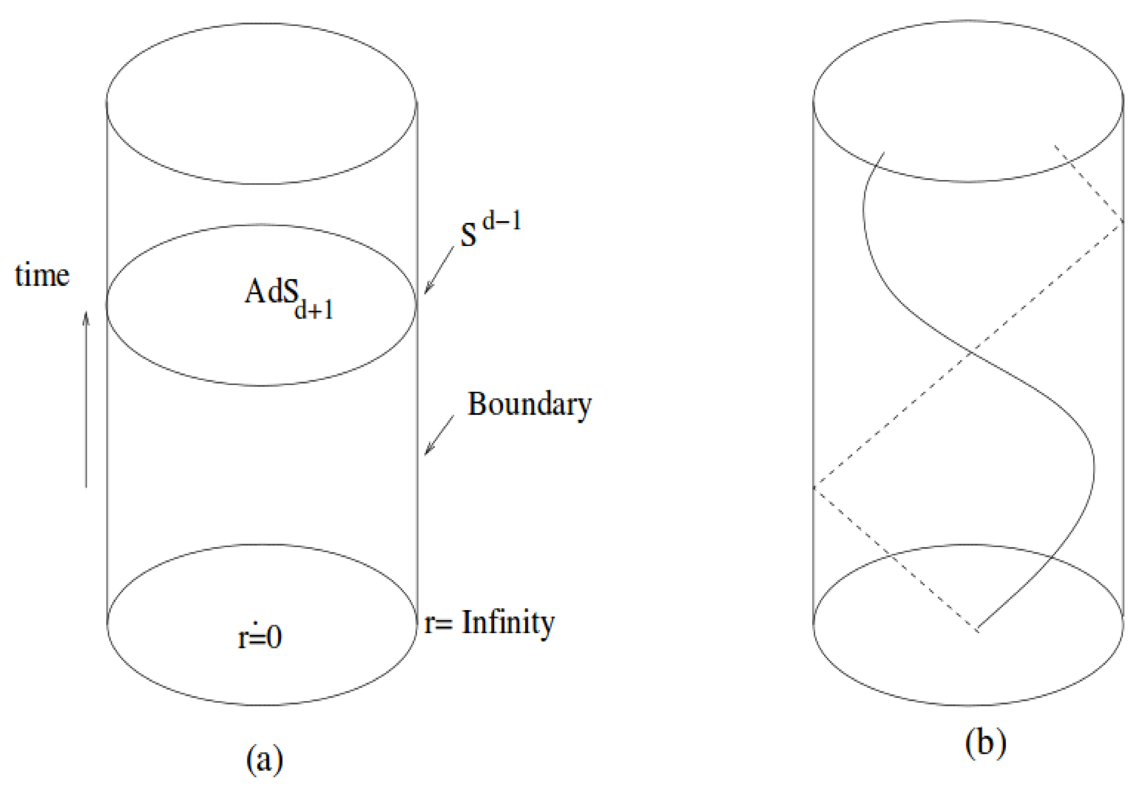

Figure 1: a) Penrose diagram for the AdS spacetime. b) Massive geodesic (solid line) and a massless geodesic (dashed line). Taken from (1).

Simulations show that, if too intense, the field will collapse gravitationally and form a black hole. Otherwise, it will scatter at the center and disperse outwards. However, as the field is confined inside the spacetime it will be reflected on the outer boundary and travel inward. What happens in this spacetime is that each time the packet is reflected at the origin, its density increases. After being reflected enough times, the field will be intense high enough to collapse.

For this spacetime we used a coordinate system in which the radial coordinate ranges from the origin, at x=0, to spacial infinity, at x=π/2. This spatial infinity is equivalent to have r = Infinity as shown in Figure 1.

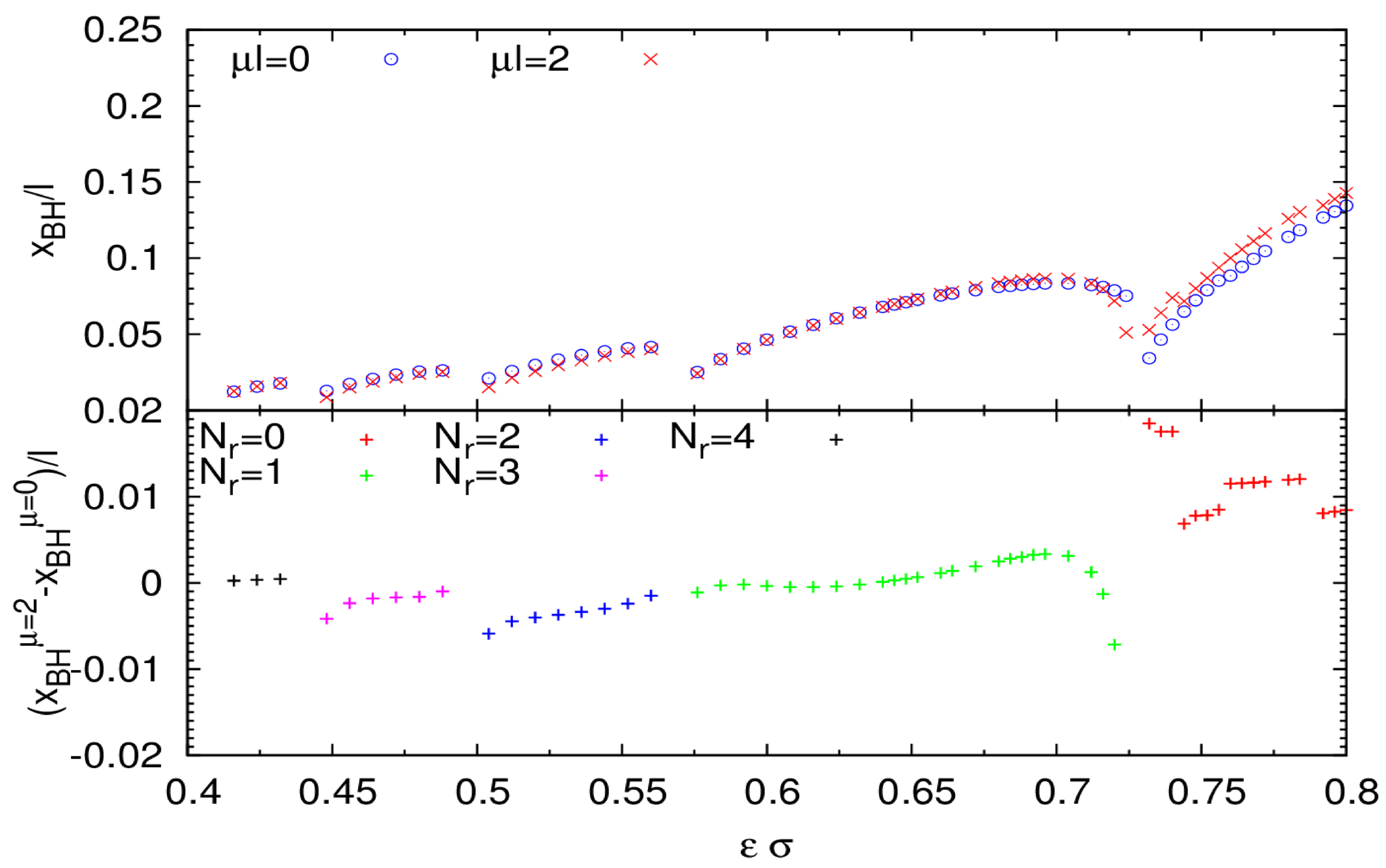

Figure 2: Direct comparison by BH radii formed through massless collapse (μl= 0) and massive collapse (μl= 2). The width/amplitude of the Gaussian wavepacket is fixed at σl = 4 (bottom). Taken from (2).

Results

Although the fields always seems to collapse into a black hole, its initial mass varies with the field's initial parameters. It is possible to see on the top half of Figure 2 the BH's initial apparent horizon radius, r_{BH}, as a function of the width, σ, with a constant initial amplitude, ε, for massless and massive fields and, on the bottom half of Figure 2, the radius difference between the massive and massless case. In order to obtain these results, the authors of (2) used a Gaussian wave packet centered at the origin. We can see that adding a simple mass term makes the initial black hole radius larger for prompt collapse (presented in red) while, for reflected fields, the BH's initial radius is smaller when we add the mass term to the field's interaction.

In this work we've also only used the simplest matter fields. There is still a long way to go before we understand what is happening at the extreme regimes.

Bibliography

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(2) Okawa, Hirotada, Jorge C. Lopes, and Vitor Cardoso. "Collapse of massive fields in anti-de Sitter spacetime." arXiv preprint arXiv:1504.05203 (2015).

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