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Black Holes as Particle Detectors

Gabriela Mocanu, a student in Daniel Grumiller's research group, writes about her project.

In our paper we wanted to describe what happens to exotic bosonic particles condensing around a rotating black hole. This really sounds more fancy than it is. We had the idea that something similar to children in the back seat of a car going "are we there yet?" is happening. Let us explain.

For our purposes, a rotating black hole is your normal matter and radiation eating friendly black hole, except that by slowing it down you could extract energy for your own benefit. We do not aim to do this personally, go to the edge and slow it down as Fred Flinstone would (the way that Fred gains energy in this way is that his feet warm up). There are particles that happily gather around black holes and do just this. We shall call them axions, although there is a garden variety of theoretical particles that do the job just as well. They are interesting because various theoretical exercises would benefit from their discovery. These axions come close to the black hole and pick up some of the rotation energy through what is called the Penrose process. It is shown that these axions do not sit around randomly but organize in what can be called a gravitational atom. The black hole is the "nucleus" and the axions are like the electrons, with the difference that, unlike electrons, they are allowed to sit together on the same chair at the cinema. Particles that do not follow this interdiction, known as the Pauli exclusion principle, are called bosons.

Let us get back to the children on the back-seat. They are staying there quietly when you leave in the morning for a cousin's place which will take a long time to reach. As time goes by, they get more and more anxious, and you could imagine them jiggling harder, thus draining energy from the driver. Based on the noises they make at some point, it even seems like although you left with three children, there are now 45 children in the back. This is what happens in the black hole-axion "atom". Draining the energy out of the black hole leads to particle formation, so in fact new axions are physically added to the cloud as time goes by. During their jiggling, children change their places on the seat, coming closer to your ears, or bumping each other, or screwing with the light from your back mirror, and thus emit all sorts of noises. In our analogy, these noises correspond to the gravitational waves to be detected in future observational campaigns. When you reach your destination, which is curiously simultaneous to when the children have the maximum energy, they suddenly relax and basically crash and fall asleep. And there is a sigh from the front seat, which is translated again in an observational signature. However, some hours from then, after the sleeping and the eating has been done, the children again have energy are ready for the way back. They have lost their memory about how long the trip takes, and are again jiggling and asking "are we there yet?" following the same energy draining pattern.

The understanding of our work relies on a few basic features. The axions gather around the black hole and get multiplied and more energetic through the Penrose process. Their density, i.e. the number of children in a cube meter of the back-seat, increases so much, approaching a critical limit, that at some point they crash and relax to another state, emitting an observational signature. But the Penrose process goes on as long as the black hole is spinning, so this chain of events occurs again and again. The novelty we propose is connected to how the axions behave near the critical limit, a behaviour called Self Organized Criticality. This is a state of the system which will lead to very distinct features in the observed gravitational waves, i.e. to those special annoying pitches (frequencies) that children show extra attention in the noise they make. Based on these features, future observational efforts will confirm or disprove our model.