Cosmic strings and boson stars

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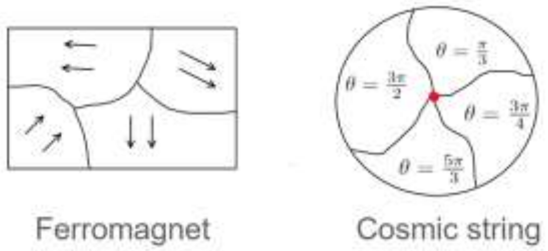
Imagine that you're going birdwatching, trying to spot them flying high up in the sky or hiding in a tree. What do you do if it's a dim and cloudy day and the birds are nowhere to be seen? You listen to their cries.

In many ways, astronomy is a cosmic game of birdwatching. Humans have been staring into the skies for millenia, with increasingly sophisticated telescopes and observatories. Yet all these tools are dependent on detecting light. How, then, can we find objects that are invisible? In 2015, LIGO achieved the first detection of gravitational waves, which ripple through the universe as massive bodies move - in a sense, we are listening to their echoes reverberating through space and time. By studying the shape of gravitational waves and gravitational radiation, we can make inferences about their sources.

Quite a few of the signals we've detected have been identified, such as those from binary black hole mergers, but many are still unknown. Unlike the birdwatchers, however, astrophysicists can go one step further. Not only can we catalogue these signals, we can make predictions: there is a wealth of theoretical astrophysical objects that behave in fascinating yet unintuitive ways, made up of entirely unfamiliar forms of matter. Mathematical equations describe what to look for and gravity gives us the how.

One such object is a boson star, composed of bosons (as opposed to particles known as fermions, such as protons and electrons). They can be very compact, like neutron stars, and may be detected by their gravitational radiation. Boson stars can act as an alternative to black holes, but they have no singularities or event horizons, hence the need to distinguish between the two. Boson stars are described by complex scalar fields, namely fields which can have values that are complex numbers and don't have a direction associated with each point.



Another cosmological object which can be modelled by a complex scalar field is a cosmic string. They are a type of topological defect, which can be explained by an analogy. Consider the two-dimensional domain walls of a ferromagnet, which separate regions where the magnetic dipoles point in different directions. Cosmic strings are one-dimensional, separating areas of space where the aforementioned complex scalar fields have different phases. While boson stars have a connection to black holes, cosmic strings may shed light on another problem related to gravity: dark matter. Their radiation can be equivalent to axions, a dark matter candidate.

Although cosmic strings and boson stars seem unrelated at first glance, being physically very different, my project seeks to shed light on possible connections between the two. There are certain similarities between their potentials, allowing for the same approach to be taken when modelling their gravitational radiation, wherein their equations of motion are separated into real and imaginary parts, then perturbed. For cosmic strings, this results in two distinct modes of radiation which behave like massive and massless fields respectively, whereas boson stars have only massive modes of radiation.

There are still unanswered questions, of course. I also investigated an object known as a Q-ball, whose potential is seemingly a boundary case between those of cosmic strings and boson stars, but whether such a transition between the two actually exists is unclear. What is clear is that there is a plethora of possibilities, with intriguing mathematical and physical consequences, waiting for us to explore.

With new developments such as gravitational wave astronomy, the wealth of astrophysical phenomena that we can observe grows ever richer. Cosmic strings and boson stars are two such objects which share various similarities and crucial differences. By understanding how these bodies behave, we take a step closer to deciphering the universe's whispers of its past, present and future.