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Summary

> *"The ancient teachers of this science," said he, "promised impossibilities, and performed nothing. The modern masters promise very little; they know that metals cannot be transmuted, and that the elixir of life is a chimera. But these philosophers, whose hands seem only made to dabble in dirt, and their eyes to pour over the microscope or crucible, have indeed performed miracles. They penetrate into the recesses of nature, and show how she works in her hiding-places. They ascend into the heavens: they have discovered how the blood circulates, and the nature of the air we breathe. They have acquired new and almost unlimited powers; they can command the thunders of heaven, mimic the earthquake, and even mock the invisible world with its own shadows." Such were the professor's words – rather let me say such the words of the fate – enounced to destroy me. As he went on I felt as if my soul were grappling with a palpable enemy; one by one the various keys were touched which formed the mechanism of my being: chord after chord was sounded, and soon my mind was filled with one thought, one conception, one purpose.*

Mary Shelley, *Frankenstein*, 1818

One of the most fascinating enigmas of mankind is the origin of the universe. Throughout the time, philosophers, astronomers, mathematicians, physicists, chemists, biologists,... have been chasing the answer to this conundrum, which is still a mystery. However, scientists have tried really hard and they have been able to follow the universe evolution backwards in time until its very first second. It is no wonder that I also wanted to participate in this hunt, although my goal is to answer slightly more modest questions.

The universe is made of particles and energy, but we only understand 5% of its content, the so-called baryonic matter, like protons and neutrons. As for the rest, we know there must exist about 27% of something we call dark matter (because we cannot see it), which so far has not been directly detected. However, the existence of a non-visible matter component is required to explain certain observations of galaxies and clusters of galaxies. And the big mystery of dark energy fills the rest of the cake, accounting for approximately 68% of the universe content. We also do not know what it is, but we know it drives the present expansion of the universe and that somehow this energy is stored in the vacuum. In view of this, ignorance might be a curse rather than a blessing.

On the bright side, we understand very well most of the processes that the universe underwent until now: from the formation of the first atoms to the gigantic clusters of galaxies. Because we understand the physics behind it, we have been able to play backwards the movie of the universe until the time of the Big Bang. But in between there was a very special moment: the first burst of light, that is called the cosmic microwave background radiation, or CMB for short. This light was emitted when the universe was approximately 380000 years old, and it travelled all the way towards us during 13000 million years! This is the oldest photograph of the universe.

The same way that the light of the Sun takes eight minutes to reach us, so we see the Sun as it was eight minutes ago, when we look at the CMB we see the universe as it was 13000 millions years ago. This light is visible with special telescopes and there is a beautiful picture of it in the first chapter of this thesis. Although we can still rewind the movie of the universe until the very first instant (because we know how the physical laws work up to the electroweak scale), we have no experiment able to measure directly any background before the CMB. Before that time, the universe was so hot that everything inside the cosmic fluid was colliding. The multiple collisions taking place did not let the light particles move freely, so not even the light could escape the cosmic fluid and travel towards us. The universe was opaque.

When the CMB was observed for the first time in 1965, there was finally solid proof that the early universe was extremely homogeneous, so extraordinarily homogeneous that the Big Bang theory was not able to explain it. This is because the standard Big Bang theory predicts a stage of decelerated expansion. Essentially, in a universe where gravity is attractive, matter tends to cluster and form regions with more density than others. In other words, gravitational attraction produces decelerated expansion and inhomogeneities, which were not in agreement with the CMB observations.

It was not until the 1980's that a solution was proposed, which could explain the homogeneity of the early universe: before the Big Bang there must exist a period of accelerated expansion! This would explain why the universe is the way it is. That period of accelerated expansion was called inflation, and it is tremendously successful. Its predictions are in remarkable agreement with the CMB experiments, and it provides an easy way to explain the peculiarities of the early universe. Indeed, what happened during the very early epoch of accelerated expansion left fingerprints in the CMB, and we are looking with a magnifying glass searching for signatures of inflation.

Now comes the role of the theoretician, who has to propose mechanisms that explain how gravity was acting as if it was repulsive. In the last thirty years, physicists have been trying to unveil the mysteries of inflation, looking for descriptions that would explain naturally the accelerated expansion. At the same time, it has been possible to test those theories to some degree with the help of the CMB data. The simplest explanation is the very presence of a single particle, such as the Higgs boson, that drove the early and brutal accelerated expansion of the universe.

At this point, the simplest models are very successful, but the experiments are becoming so accurate that we are starting to see hints of anomalies that we are not quite sure how to explain with these simplest models. These anomalies might be there or not, but we want to be ready.

In addition, the knowledge of physics during the first second of the universe is not so robust. When gravity becomes as important as electromagnetic or nuclear forces and the quantum and gravitational effects are comparable, our standard theories simply do not work. Enormous efforts have been made in this respect by elaborating theories such as superstrings and supergravity. Describing inflation in the context of these theories is an indirect way to test them.

In this spirit, in this thesis I have started a search, together with my collaborators, for the presence of additional particles during inflation. These particles are expected to be there if inflation is to be described by new physics, participating in the expansion of the early universe. We have investigated how to incorporate these additional particles in our theories, in a way that the theory is still well understood and consistent. More importantly, we have also calculated the effect of these additional particles in the observations of the CMB, so that we make predictions in agreement with the experiments. After four years, we do not have a conclusive evidence for these additional particles yet. But the current experiments are already potentially sensitive to the presence of these particles, and it might be that in the very near future they detect new features. Perhaps these features can be explained by the presence of additional particles, all together playing to inflate the very early universe. They might be already giving us subtle hints through the picture of a very young universe...