A new language for cosmology

Op 2 juli 2025 promoveerde Facundo Rost op zijn proefschrift "A Novel Language for Spinning (A)dS Correlators". In dit Engelstalige artikel legt Facundo uit waar zijn promotieonderzoek over ging, en naar welke "nieuwe taal voor de kosmologie" de titel van zijn proefschrift verwijst.

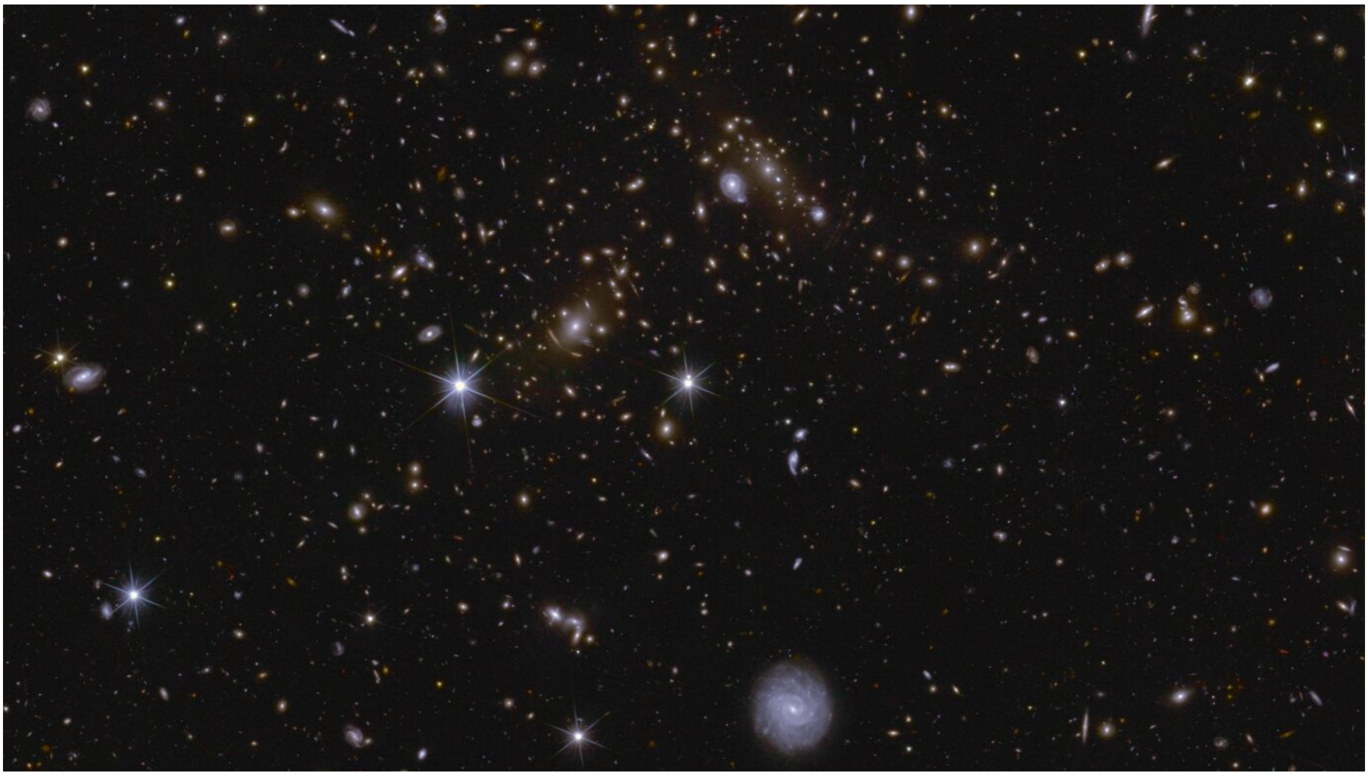

Figure 1. The Universe and its structure. In some regions that we observe today, there are a lot of galaxies accumulated, while other regions are practically empty. Image: ESA/Euclid/Euclid Consortium/NASA, image processing by J.-C. Cuillandre, E. Bertin, G. Anselmi.

When we look at the Universe today, we see that it has a certain structure: In some regions there are many galaxies, while in others there are very few. To understand the origin of this structure – why galaxies gathered in some regions of the Universe and not in others – cosmologists study the history of the Universe as a whole.

If we go back in time about 13.8 billion years, there was a very short period called *inflation* (see this previous article for more details). It happened immediately after the Big Bang, in the first 10^{-35} seconds (one hundredth of a decillionth of a second), when the Universe expanded from being incredibly small to enormously large in an instant. During this period, the Universe was microscopic, and its energy was extremely high, which caused many tiny *quantum fluctuations* to happen. In simple terms, this means that particles were being created and destroyed out of nowhere in different parts of the Universe.

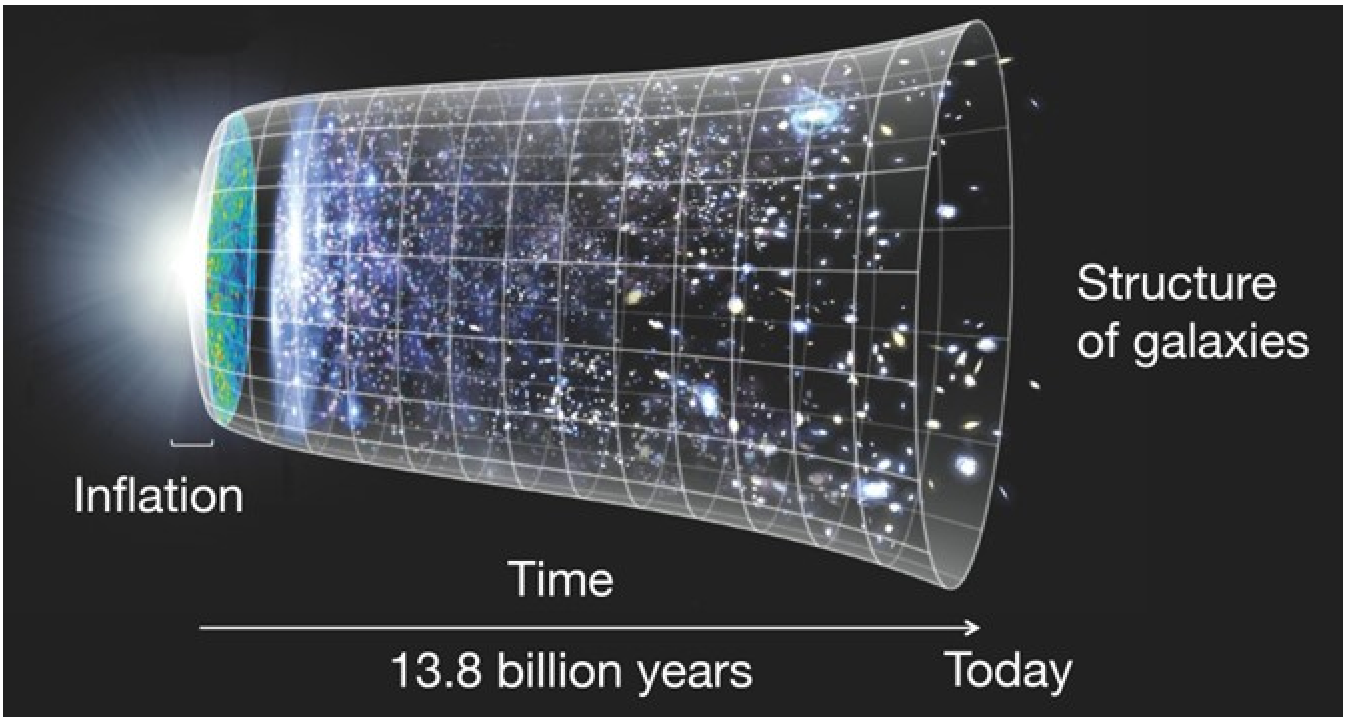

Figure 2. Inflation. The brutal expansion of the Universe during inflation, immediately after the Big Bang, stretched tiny quantum fluctuations to enormous sizes. This eventually led to the distribution of galaxies we observe today. Image: NASA/WMAP Science Team.

Remarkably, the violent expansion of the Universe during inflation stretched these small, microscopic fluctuations to huge, cosmological scales, leading eventually to the formation of galaxies across the whole Universe. In this way, inflation provides an astonishing mechanism where extremely small, subatomic physical processes are the cause of physical processes of enormous size, such as the current distribution of galaxies in the Universe. Importantly, there was more particle creation and annihilation in some regions than in others, which implied that more galaxies eventually formed in some regions, while others remained relatively empty. This is how we currently understand the origin of the structure of the Universe. In essence, the galaxies we see today originated from tiny quantum ripples in the very early Universe.

To study the consequences of these quantum fluctuations, cosmologists use the so-called *cosmological correlators*. These are mathematical quantities that act like fingerprints of the quantum fluctuations during inflation; traces that the Universe kept after that period ended. They measure how different particles in different regions of the Universe were correlated at the end of inflation as a result of those earlier fluctuations. You can find more details about these correlations in this previous article.

Both the distribution of galaxies we see today, and the oldest "photo" of the Universe – the Cosmic Microwave Background – are determined by these cosmological correlators. These are the two main ways in which we can "measure the Universe as a whole". Therefore, understanding these correlators in detail is essential for learning about the Universe and its history.

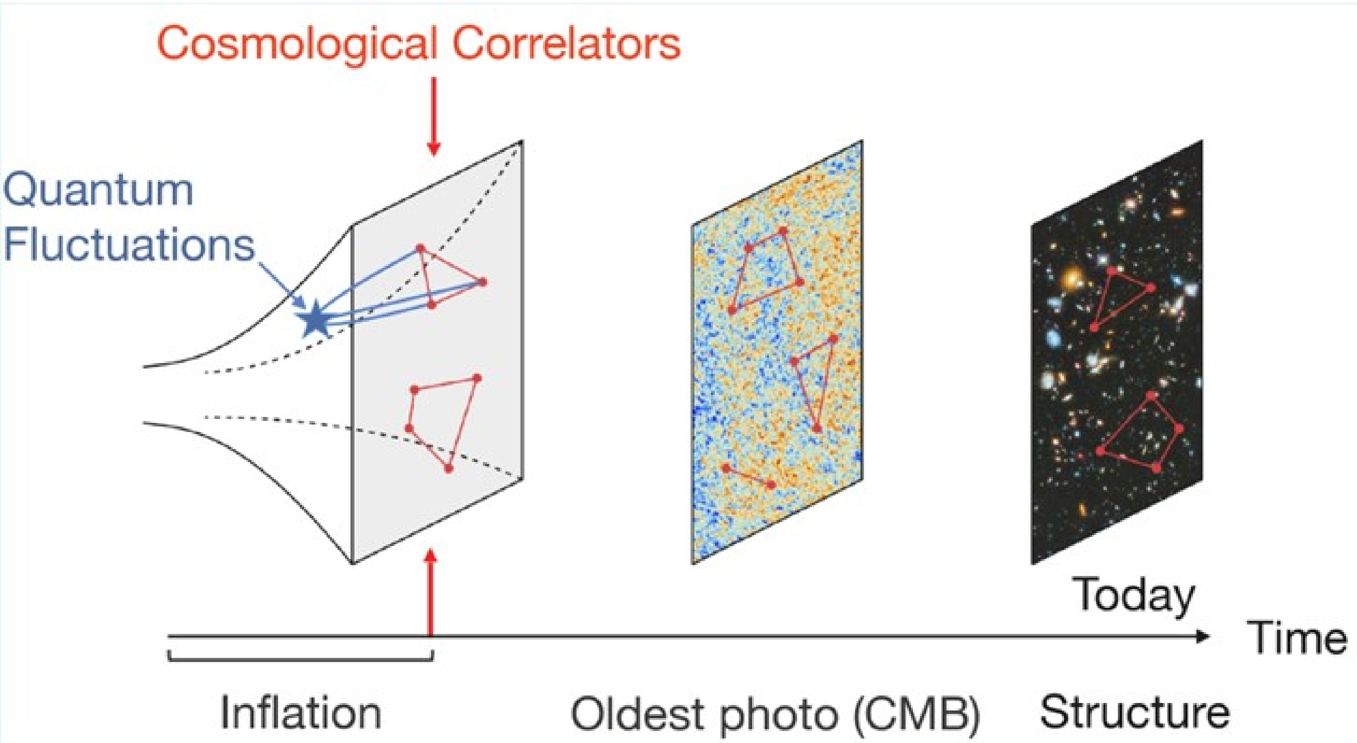

Figure 3. Cosmological correlators. Cosmological correlators are the imprints that survive at the end of inflation due to previous quantum fluctuations. They eventually determine the oldest picture we can see of the Universe – the so-called Cosmic Microwave Background (CMB) – as well as the structure of galaxies across the whole Universe. Image by Carlos Duaso Pueyo; background images by ESA and the Planck Collaboration and NASA, ESA, H. Teplitz and M. Rafelski (IPAC/Caltech), A. Koekemoer (STScI), R. Windhorst (Arizona State University), and Z. Levay (STScI).

Unfortunately, cosmological correlators are extremely complicated mathematical objects. Some of their known formulas are so long that they can fill an entire page. However, we have reasons to believe that these objects are actually much simpler than they seem. Indeed, they only look complicated because we are using an inconvenient mathematical language to describe them.

The goal of my doctoral thesis was to find a new way to describe these correlators: a new language that could reveal their hidden simplicity. Indeed, together with Daniel Baumann, Grégoire Mathys and Guilherme Pimentel, we discovered such a language. It amounts to describing these correlators in terms of some planes in space-time, called *twistors*, rather than in terms of points. Notably, this allows us to express many of these complicated correlators as beautiful formulas that can fit on a single line.

The goal of this new language is not only to make these correlators easier to write down. By simplifying them, we can understand their mathematical structure much better, and gain new insights into the physical theory behind them. Moreover, this might even lead to a completely novel way of thinking about the Universe itself.

Let me conclude with some exciting ideas for the future along these lines. It is likely that the concept of time did not make sense at the very beginning of the Big Bang – that it somehow “broke down”. If so, we may need a way to describe the Universe that does not rely on time at all. We suspect that our new language could point towards such a description.

Instead of thinking of cosmological correlators as the results of earlier quantum fluctuations, this new approach suggests that they may be viewed as the volumes of abstract geometries with no notion of time whatsoever. In this picture, time is not something fundamental – it would emerge from these geometries, just like the notion of water appears when we look at many atoms and molecules from far away. In other words: time itself might emerge from this timeless picture at the birth of the Universe.