Exploring the Early Universe

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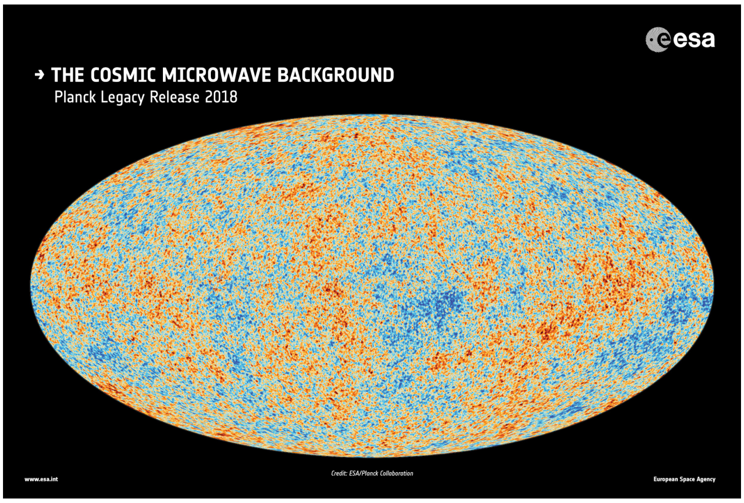
One of the primary aims of the Boustany Foundation is to support the pursuit of knowledge in many diverse areas. As a PhD student at the Institute of Astronomy, Cambridge, my field of interest is cosmology, the study of the Universe as a whole. In particular, my colleagues and I use the most ancient light we can observe, emitted over 13 billion years ago, to learn more about the history and makeup of the Universe.



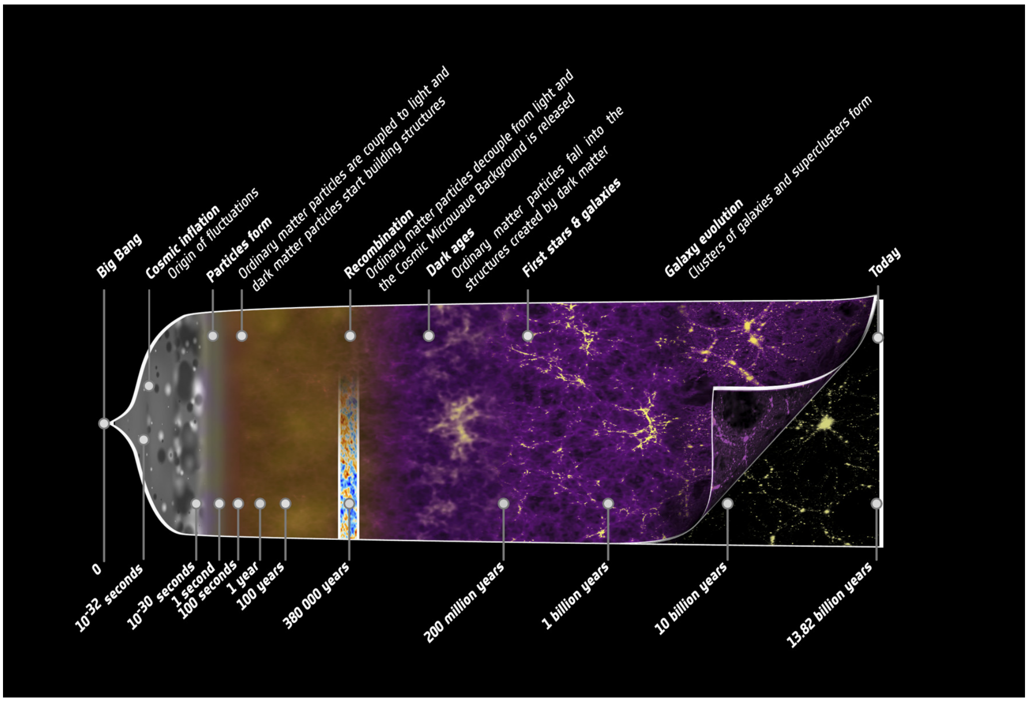
Planck *map of the CMB on the full sky. The temperature variations pictured reflect fluctuations in the density of the early plasma. (Credit: ESA/Planck Collaboration)*

According to the standard picture of the early Universe among scientists today, everything we know started out in an extremely hot, dense state, a soup of subatomic particles and light that existed within a fraction of a second of creation. This quickly expanded and cooled until about three minutes in, when nuclei of the light elements hydrogen, helium, and lithium had formed. For the next 380,000 years, the Universe was filled with a nearly uniform, featureless plasma marked only by regions of very slightly more or less gas. These small fluctuations of the density evolved over time under the influences of gravity and pressure; eventually the most dense regions would undergo gravitational collapse and become the seeds of the galaxies and clusters of galaxies that we observe now. Fortunately for us as scientists, light from that plasma, emitted over 13 billion years ago, is still able to reach us and be measured today. That light, present across the whole sky, serves as a map of density fluctuations in the early Universe known as the Cosmic Microwave Background (CMB). The properties of this map depend on the initial density fluctuations, plus the laws of gravity and overall composition of the Universe, which affect their evolution. Therefore by comparing these fluctuations to predictions made with physical models, we can learn more about gravity and the makeup of the cosmos.

There have been several waves of CMB experiments since its discovery in 1965, one of the most prominent being the European Space Agency's *Planck* satellite which released its final full analysis in 2018. The latest data from *Planck* has largely reinforced the current standard cosmological model (see here for details). This is a picture of a Universe that began with a period of [very rapid expansion]() of space and which today is dominated by [dark matter]() – an mysterious kind of matter that interacts gravitationally but not with light – and [dark energy](), which acts like a force countering gravity and driving galaxies away from each other faster and faster.

Current (eg [1], [2]) and upcoming ([3], [4], [5]) experiments, largely from the ground, aim to further improve on *Planck's* findings by measuring the CMB to better resolution and with a particular focus on its polarization, which carries additional information. These measurements will allow us to study exciting new science questions. One primary goal is to search for key signatures of processes governing the formation of the original density perturbations, to better understand the earliest moments of the Universe. We can also search for signs of new, previously undiscovered particles and gain a better understanding of known light particles (neutrinos) from their gravitational effects on the gas. Furthermore, CMB experiments will complement information from upcoming optical surveys (see [6], [7], [8]) of billions of galaxies to further test the laws of gravity and contribute to our understanding of dark energy.

The measurements to be made are challenging, and require both new technologies and innovative analysis techniques. Much of my own work is in carefully comparing different CMB data-sets so that we can be sure of their consistency and accuracy, and optimally combining them to learn as much as we can. This helps us to be confident in our findings in the face of difficult experimental challenges, while extracting all the information possible out of the data. Despite the challenges, there is great possibility for discovery in the near future that will help us better understand the Universe as it was at the very beginning, its makeup today, and even its eventual fate far in the future.



The History of the Universe. Credit: ESA - C. Carreau