The Cosmic Microwave Background

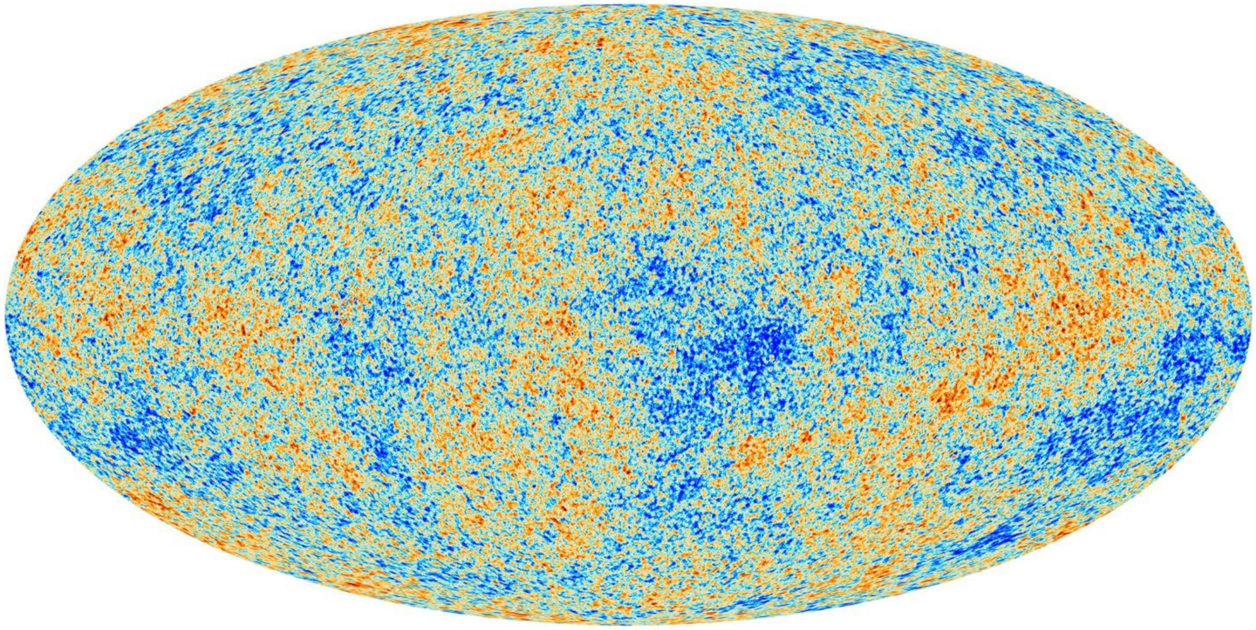
As a faint glow of the Big Bang, the Cosmic Microwave Background (CMB) offers invaluable insights into the early ages of the Universe.

This ‘background’ radiation – because it appears to emanate from all directions with the same intensity – is an integral part of the very fabric of the Universe, i.e. space-time. As space-time stretches under the effect of expansion, the wavelength of the CB increases. Today, it is detected in millimetre radio waves (around 1.9 mm), appearing as typical of the radiation of a blackbody at a temperature of 2.725 K.

At the end of the primordial nucleosynthesis era, the Universe was still so hot that newly-formed atomic nuclei and electron moved freely through a medium in which blackbody radiation, then extremely hot, was prevalent. This medium also abounded in dark matter particles, but these could interact with other components only through gravity. Meanwhile, interactions between photons from the blackbody radiation and the free electrons that filled the Universe were well underway.

This state persisted until the Universe cooled enough for electrons to lastingly combine with nuclei and form the first atoms. This recombination occurred 380,000 years after the Big Bang, when the temperature had dropped to 3,000 K, at which point ambient photons no longer had enough energy to tear electrons off atoms. With the disappearance of free electrons, the Universe became transparent to its own radiation, which has been travelling freely ever since.

Prior to recombination, the Universe was also filled with waves propagating in the medium through which they passed, like sound propagating through air. These oscillations ceased with recombination, but their effects remained imprinted on the CMB, where they can be perceived today as tiny temperature fluctuations of



Credit: ESA/Planck

about 100 μK. The same oscillations generated excess densities that evolved during the dark ages of the Universe to form large concentrations of matter which would later become galaxies and galaxy clusters.

Studying the Cosmic Microwave Background enables scientists to reconstruct the state of the Universe at the time of recombination. Further, the detailed analysis of the CMB's tiny temperature fluctuations reveals the characteristics of the oscillations that produced them. This provides crucial data about the Universe before recombination, right down to the most primordial phases. The profound interest of the scientific community in this field is evidenced by two Nobel Prizes in Physics already awarded for research on the Cosmic Microwave Background. The 1978 prize honoured Arno Penzias and Robert Wilson for their discovery of the CMB, and the 2006 prize was awarded to John Mather and George Smoot for measuring the CMB's blackbody spectrum and detecting its anisotropies.

CMB fluctuations

This image of the entire sky uses a colour scale to represent the temperature fluctuations of the Cosmic Microwave Background, as deduced from the data collected by the Planck satellite. Dark blue areas indicate the coldest regions (486 μK below the mean temperature of 2.725 K), while dark red areas represent the hottest regions in dark red, the hottest (538 μK above the mean temperature).

Translated from 'Le rayonnement de fond cosmologique',* Passeport pour les deux infinis*, IN2P3/Dunod, https://pass2i.ijclab.in2p3.fr/ (French); updated with ICHEP2024 conference (https://ichep2024.org) for IPPOG