The cosmic backgrounds of the Universe

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Abstract

An informative vision of the cosmic background of microwaves (photons), neutrinos and gravitons is presented, as well as a speculation about other possible cosmic backgrounds. Its relevance in Physics, Astrophysics and Cosmology is indicated from a simplified intuitive physical and mathematical point of view.

1 Introduction

The Astrophysics and Cosmology of the Big Bang theory [1, 2, 3] predicts the existence of fundamental particles created in the early Universe that have survived to the present day. A dramatic example is the Cosmic Microwave Background[1]. The creation of the CMB is due, as is known, to the creation of the first atoms (fundamentally hydrogen), when the early Universe reached about 380000 years of age when it cooled from the initial singularity in Planck time. Much is still unknown about what happened before the formation of the CMB, although we certainly know that the Universe was very hot, and the nuclei of the lightest atoms had to form, hadronize protons and neutrons from quarks, and also at some point there will be electroweak symmetry breaking, the selection of the current vacuum (we don't know if it is the true vacuum or just a metastable one) of the Higgs field that permeates the entire Universe, and possibly the Universe undergoes a period of cosmic inflation after the Planck time, or otherwise the Universe we observe could hardly have formed with its current structure and homogeneity.

2 The Cosmic Microwave Background(CMB)

The existence of the CMB is firmly established. Since its discovery by Penzias and Wilson, and its original satellite observation by the COBE (COsmic Background Explorer) satellite, both WMAP (Wilkinson Microwave Anisotropy Probe, NASA) and Planck (ESA) have made not only maps with unprecedented precision of the CMB , and its photon temperature [1] (currently, we have temperature $T_{CMB} = T_\gamma = 2.7255\ K$), but also its anisotropies [2]. The most accurate image of the CMB currently is the one given to us by the Planck mission and collaboration [3]. The CMB essentially corresponds to the electromagnetic radiation from a black body, which due to the enormous time lapse since its creation is now measured in the microwave region of the spectrum, making it invisible to the naked eye. However, elementary mathematics shows us that the energy density and the number of photons at a temperature T_γ of a black body are, respectively (it is left as an exercise for the reader to find their values for the observed CMB):

$$u_\gamma = \frac{U}{V} = \frac{\pi^2 k_B^4 T_\gamma^4}{15\hbar^3 c^3} \qquad n_\gamma = \frac{N}{V} = \frac{2\zeta(3)}{\pi^2}\frac{k_B^3 T^3}{\hbar^3 c^3} \tag{1}$$

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[1] Also called CMB, for Cosmic Microwave Background.

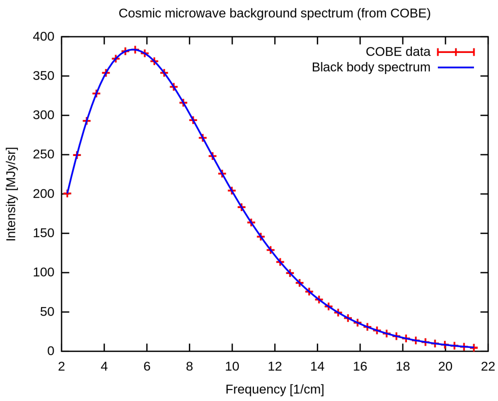

Figure 1: CMB spectrum captured by the COBE satellite. It corresponds to the spectrum of a hot black body with a temperature of about 3 K.

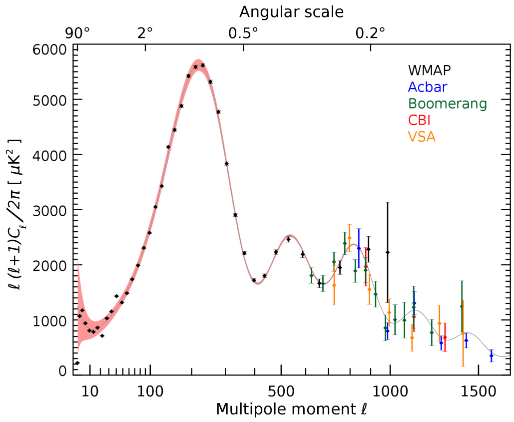

Figure 2: Anisotropies of the CMB power spectrum.

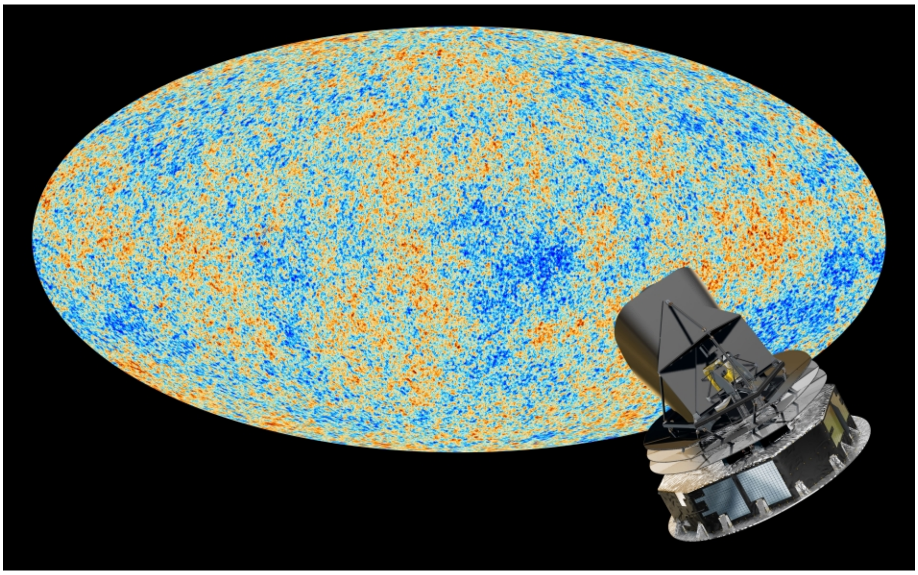

Figure 3: The most accurate CMB map is from the Planck (ESA) mission.

3 The cosmic neutrino background(CNB)

A result less known to the public is the existence of neutrinos as subatomic particles, and also the fact that the Big Bang predicts that neutrinos "decoupled" from the primordial plasma much earlier than the photons of the CMB. Neutrinos freely roam the Universe from about the first second of its creation (!). One would expect that neutrinos from the first second of the Universe would also be spectrally separated and distributed at all frequencies (albeit with a Fermi-Dirac distribution, rather than a Bose-Einstein one), producing a cosmic background of neutrinos depending on temperature. The Big Bang model predicts that the temperature of these cosmic neutrinos is related to that of the CMB in a simple way, through the following equation:

$$T_{0,\nu} = \left(\frac{4}{11}\right)^{1/3} T_{0,\gamma} \approx 1.95\ K \tag{2}$$

The derivation of this equation implies (see e.g., [1, 2]), that the cosmic background of neutrinos is of lower temperature than that of photons and assumes only that neutrinos are Standard Model particles, and since neutrinos interact much more weakly than photons, the Cosmic Neutrino Background (also called CNB[2]). It is noteworthy that if the neutrinos had additional degrees of freedom, the temperature

[2]From Cosmic Neutrino Background, in English, although the acronym $C\nu B$ is also used.

of the CNB would be lower than the previous value.

4 The cosmic graviton background and beyond

Knowing the CMB better (for example, by measuring the polarization of its photons), and measuring the CNB (still undetected) would help you understand the origin, formation, and future of our Universe. But you can go further, and ask yourself about the cosmic background of other fields and particles. What about cosmic rays? Gamma rays? Maybe in the future the cosmic background of dark matter particles or axions? However, despite the non-existence of a quantum theory of gravitation, the Big Bang theory itself is so powerful that it allows us to deduce, assuming that the degrees of freedom and particles are only from the Standard Model of Elementary Particle Physics, the temperature of a cosmic background of cosmic gravitons (CGB) or relics from Planck's time itself, when gravity became decoupled from the rest of the fundamental interactions. The temperature of this cosmic background would also follow a Bose-Einstein distribution, and would be related to the temperature of the CMB as follows (see [2] and [4] for more details):

$$T_{0,g} = \left(\frac{g_S(T_0)}{g_S(T_P) - 2} \right)^{1/3} T_{0,\gamma} \approx 0.9\ K \tag{3}$$

and where $g_S(T_0) = 3.91$ is the effective number of degrees of freedom at the current epoch excluding gravitons, and $g_S(T_P)$ is the effective number of degrees of freedom prior to the decoupling of gravitons at Planck's temperature. Again, assuming only the Standard Model, we can assume that $g_S(T_P) = 106.76$. This derivation depends fundamentally on the Standard Model, other models would produce temperatures lower than the one estimated above. And even, one could or should expect a cosmic background of these particles, were their detection more or less difficult.

5 Conclusion and future

The Big Bang Theory and Cosmology predict the existence of a series of cosmic backgrounds of particles (CMB, CNB, CGB) of temperatures $3\ K, 2\ K, 1\ K$, in a kind of countdown rule 3,2,1...Kaboom! It is to be expected that if Nature possesses additional fields and particles to those of the Standard Model, other cosmic backgrounds exist (of axions and other dark matter particles, for example). Also, the cosmic background of gravitational waves could and should be studied according to the frequencies, and that map of gravitational waves (not to be confused with the cosmic background of neutrinos) would still provide valuable information about certain stages of the Universe for which vision with electromagnetic waves (microwave or not) would be impossible. In short, we still have a lot to learn from the cosmic background radiation of a multitude of particles. Neutrinos or gravitons are 2 of those that we hope to observe cosmic backgrounds, but it will certainly be much more exciting to find and measure cosmic backgrounds of new fields and particles that we find in the future.

References

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[2] *Cosmology*, Steven Weinberg. Oxford University Press.

[3] *Lectures on Astrophysics.* Steven Weinberg. Cambridge University Press.

[4] *The challenge of ruling out inflation via the primordial graviton background*, Sunny Vagnozzi and Abraham Loeb. ArXiv: `https://doi.org/10.48550/arXiv.2208.14088`