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The Cosmic Microwave Background/Le rayonnement fossile à 3K

Foreword

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Abstract

We introduce the main issues related to the new cosmological advances coming from observations of the Cosmic Microwave Background (CMB). These issues are then detailed in the following articles of this special CMB volume. ***To cite this article: F.-X. Désert, C. R. Physique 4 (2003).***

Résumé

Avant propos. Nous présentons les points principaux liés aux nouvelles avancées cosmologiques provenant des observations du fonds diffus cosmologique à 3K (CMB). Ces points sont ensuite détaillés dans les articles suivants de ce numéro spécial CMB. ***Pour citer cet article : F.-X. Désert, C. R. Physique 4 (2003).***

1. Presentation

That "*This excess temperature is, within the limits of our observations, isotropic, unpolarized, and free from seasonal variations.*" is the conclusion of the discovery article of an excess noise in the sky with a temperature amounting to 3.5 ± 1 K. Arno A. Penzias and Robert W. Wilson [1] thus published in 1965 a neutral article on the first detection[1] of the Cosmic Microwave Background (CMB) and containing no theoretical prejudice. The Nobel-Prize winners just mentioned the accompanying interpretation paper by Dicke, Peebles, Roll, and Wilkinson [3]. Gamow and Peebles were among the first cosmologists to study the essential link between the nucleosynthesis of the light elements (D, He, Li) and the remnant radiation of a hot phase of the Universe, two of the three pillars of the modern Big Bang scenario (the third one being Hubble's expansion law). The last 40 years have seen a whole new scientific discipline at the frontiers of astrophysics, cosmology, particle physics and solid-state physics built upon the unique wealth of information that is encoded in the temperature, anisotropy and polarization of the CMB. Rapid advances have been recently made in experimental cosmology with the CMB, starting from COBE, then QMAP, TOCO, BOOMERANG, MAXIMA, DASI, ARCHEOPS and WMAP to name but a few. Reaching the geometry and content of the Universe has just become possible. This can be compared to the GPS system on Earth, a kind of 17th century geographer's dream. This special issue of *Comptes Rendus Physique* tries to give an updated view of some of the principal modern topics related to the CMB. Rather than having an exhaustive review, we have chosen to illustrate some of the critical points (experiments, data analysis, early universe theory, astrophysical foregrounds, links with other cosmological tools) in the CMB field, with articles from experts of the French and international communities, including two members of the French Academy of Sciences. A perspective in the CMB field is touched upon with articles on PLANCK and polarization measurements.

Bouchet, in the introductory article of this issue, reviews the major improvements that were accomplished from COBE–DMR (1990), which provided the first evidence for CMB anisotropies, up to the latest one-year old results from WMAP (2003), the

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[1] A near detection was hinted at, in 1957, by Denisse, Lequeux and Le Roux [2].

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NASA Wilkinson Microwave Anisotropy Probe named after Dave Wilkinson, one of the founders of the instrument, who died in September 2002. Bouchet gives a theoretical background for interpreting the CMB anisotropies and polarization, the main focus of the following articles. As a reminder, the tiny fluctuations of temperature, seen in the cover picture as measured by WMAP [4], have typical peak-to-peak amplitudes of ±200 μK, that correspond to relative variations of $\frac{\Delta T}{T} = \pm 7 \times 10^{-5}$. They are a fossil trace of the drum beat of the Universe (the so-called acoustic waves) just before it became transparent. They span angular scales from half a degree to ninety degrees. As a comparison, if one folded the celestial sphere on the surface of the Earth, the fluctuations would translate in height to no more than 500 m, say the highest summit of Luxembourg, and in angular span from the width of Luxembourg up to the extent of the Pacific Ocean.

The temperature and the blackbody nature of the CMB have been a long standing issue which is summarized by Bouchet and Puget. The instrument FIRAS on COBE gave a definitive answer [5]. The present absolute temperature of the CMB is $T_{\text{CMB}} = 2.725 \pm 0.001$ K, with a blackbody nature at better than an rms level of 5×10^{-5} peak emission, which has not been improved by other instruments since.

Examples of working bolometric instruments are then given. The article by Stompor, Hanany, Abroe, et al. describes one of the most sensitive instruments: MAXIMA. Although they cover less than 0.5% of the sky, they are able to show a remarkable consistency with maps of WMAP for the common region of the sky and WMAP angular power spectrum. On the other hand, ARCHEOPS results reported by Hamilton, Benoît et al. anticipate on the Planck HFI instrument, both technically and scientifically, in covering a large fraction of the sky at millimetre and submillimetre wavelengths.

The final word on anisotropies should be given by the PLANCK mission in 2007. Bouchet, Piat and Lamarre give an update of the PLANCK capabilities. In particular, the High Frequency Instrument (HFI) uses innovative cooling and detector assemblies. This instrument should have a sensitivity such that it is close to achieving fundamental detection limits set by the cosmic variance (we have only one celestial sphere at our observing disposal) and photon noise due to the CMB itself (i.e. the temporal granularity of its own incoming photons).

To make maps of the CMB anisotropies, one does not rely yet on cameras like CCDs in the visible wavelength domain. Rather, single detectors, coupled to a telescope, are scanned over the sky in a complex raster pattern. The methods of reconstructing maps out of the raw data coming from this observing technique are quite sophisticated, a bit like a video image can be made out of the electronic beam raster scan on a TV screen. They are reported here by Hamilton. Then one has to measure the root-mean-square fluctuations at various angular scales, the so-called CMB power spectrum C_l. Hamilton describes the techniques to measure it, while Douspis establishes the methods to compare model predictions with the power spectrum and the different ways of extracting bounds on the cosmological parameters: the Hubble constant, the age of the Universe, the curvature, the matter and energy contents, the primordial fluctuation spectra.

Already, Penzias and Wilson [1] mentioned what has become a permanent fight for experimenters: sidelobe and point source contaminations. Here, Lagache and Aghanim deal with the ways various types of extragalactic sources can contaminate the pristine CMB on its way to solar-bound telescopes. On the other hand, they show all the astrophysical by-products one can learn from disentangling the CMB and the sources.

Giard and Lagache also show how galactic foreground emissions must be somehow removed to clean the CMB data. The understanding of the cold processes in the Milky Way is a very valuable by-product of cosmological studies of the CMB.

Blanchard, Bartlett and Douspis compare the advances in the knowledge of the cosmological parameters from the CMB with respect to other techniques. Although a surprising convergence of results is obtained from independent observational tools, toward the so-called ΛCDM model, there are still some 'left over' bits which do not fit into the big picture.

Kaplan, Delabrouille, Fosalba and Rosset review the rather new theoretical motivation for CMB polarization measurements. Delabrouille, Kaplan, Piat and Rosset describe the ever-increasing number of new experiments specifically designed for that goal. Particle physics has found a new tool, in the CMB access to the early universe, to study matter in a state unreachable with present particle accelerators.

Nowadays, the data cannot be shown without referring to the standard inflation scenario which has so far withstood experimental scrutiny for the last twenty years. Parentani gives a general account of the success of this huge addition to the standard Big Bang.

A Strasbourg physics Professor once asked me: "*Which side of cosmology are you working on? The Universe is all about symmetry like a crystal or the Universe is all about signal to noise ratio*." Most of the articles show the struggle to obtain valid signals while one article by Uzan and Riazuelo shows that the idea of a non-trivial topology of the Universe has some appeal. Well, the jury is still out and the CMB can certainly help in answering that falsifiable question too.

Langlois reviews other primordial perturbation modes which can leave some imprint on the CMB. These isocurvature modes could help understanding some of the physics in the early Universe.

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