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PLANCK-LFI scientific goals: Implications for the reionization history ☆

L.A. Popa [a,e], C. Burigana [a,*], N. Mandolesi [a], R.C. Butler [a], F. Cuttaia [a], F. Finelli [a,b], E. Franceschi [a], M. Galaverni [a,c], A. Gruppuso [a], M. Malaspina [a], G. Morgante [a], F. Paci [a,d], P. Procopio [a,c], M. Sandri [a], L. Stringhetti [a], L. Terenzi [a], L. Valenziano [a], F. Villa [a], J. Zuccarelli [a,c]

[a] INAF IASF Bologna, Via Gobetti 101, 40129 Bologna, Italy
[b] INAF Osservatorio Astronomico di Bologna, Via Ranzani 1, 40127 Bologna, Italy
[c] Dipartimento di Fisica, Università degli Studi di Ferrara, Via Saragat 1, 44100 Ferrara, Italy
[d] Dipartimento di Astronomia, Università degli Studi di Bologna, Via Ranzani 1, 40127 Bologna, Italy
[e] Institute for Space Sciences, Bucharest-Magurele, Str. Atomostilor 409, Ro-077125 Bucharest, Romania

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Abstract

The PLANCK mission will be crucial to test the robustness of the ΛCDM concordance model since the relevant cosmological parameters will be measured with much better sensitivity.

As the final scientific performance of PLANCK depends not only on the instrumental performances, but also on the detailed knowledge of the behavior of the astrophysical foregrounds, systematic effects and their interplay, in this paper we discuss these aspects from the point of view of the CMB angular power spectrum recovery.

As an example of PLANCK scientific goal we discuss the possibility to constrain the reionization history of the Universe by using E-mode polarization CMB measurements.

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Keywords: Cosmology: cosmic microwave background; Large-scale structure; Dark matter

Contents

1. Introduction

The confluence of the experimental data on cosmic microwave background (CMB) anisotropies, large-scale structure (LSS) galaxy surveys, supernovae luminosity

☆ This work has been done in the framework of the PLANCK LFI activities.

* Corresponding author.
E-mail address: burigana@iasfbo.inaf.it (C. Burigana).

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distance, Lyman-α forest and the Hubble parameter, have lead in specifying the ΛCDM model as the cosmological concordance model (see Spergel et al., submitted for publication and references therein). According to this model the Universe is spatially nearly flat with energy density of $\Omega_m \simeq 0.24$ in matter, $\Omega_b \simeq 0.044$ in baryons, $\Omega_\Lambda \simeq 0.76$ in cosmological constant, an Hubble constant of $H_0 \simeq 72$ km s^{-1} Mpc^{-1} and adiabatic initial conditions of the density fluctuations.

The direct confirmation of this theory was the detection of the acoustic Doppler peak structure in the CMB angular power spectrum. Further successes are related to the correct prediction of the hierarchical structure formation via gravitational instability, the abundances of clusters on small redshifts, the spatial distribution and the number density of galaxies, the LSS matter power spectrum, the Lyman-α amplitude and spectrum.

Despite its successes on large scales, the ΛCDM model produces too much small scale structure. Some issues of ΛCDM on small scales includes: contradiction between the observed linearly rising galaxy rotation curves versus $1/r^\alpha$ ($1 < \alpha < 1.5$) predicted density cusps, too much substructure compared with the observed numbers of satellite galaxies in the Local Group, the baryon angular momentum problems (it predicts too much baryonic material with low angular momentum to form the observed rotationally disk galaxies). In general, the observed halos have softer cores, lower concentrations and are less clumped than predicted by the ΛCDM model.

Also, an early reionization of the Universe, favoring the early collapse of structures as indicated by the recent WMAP polarization measurements (Page et al., submitted for publication), can be explained in the framework of the ΛCDM model only under extreme assumptions on star formation.

The significances of these discrepancies are still disputed and the astrophysical solutions (stellar feedback, dynamical heating, heavier stellar initial mass function) or rather drastic solutions involving the modification of the fundamental physics (as the change of the gravity law) have been proposed (see e.g. Silk, 2004 and the references therein).

In this theoretical and experimental frame, the PLANCK mission[1] will be crucial to test the robustness of the ΛCDM concordance model since the relevant cosmological parameters will be measured with much better sensitivity. The two instruments at cryogenic temperatures on-board the ESA PLANCK satellite, the Low Frequency Instrument (LFI) based on differential radiometers (Mandolesi et al., 1998) and the High Frequency Instrument (HFI) based on state-of-art bolometers (Puget et al., 1998) at the focus of a 1.5 m aperture off-axis Gregorian telescope, will image the whole sky with combination of sensitivity ($\Delta T/T \sim$ some $\times 10^{-6}$ μK/K), angular resolution (to $\simeq$30–5 arc min) and frequency coverage (30–857 GHz) that will enable to produce maps of the whole sky in nine frequency channels. The combination of data from LFI and HFI will give to PLANCK the imaging power, the redundancy and the control of the systematic effects and foreground emission needed to achieve its scientific goals.

The principal observational objective of the PLANCK mission is to measure the temperature fluctuations of the CMB with an accuracy set by the fundamental astrophysical limits. All LFI channels and four of the HFI channels will also measure the linear polarization of the CMB which encodes not only a wealth of cosmological information, but also provides a crucial probe of the ionization history of the Universe during the time when the first stars and galaxies formed.

The CMB maps will include also other astrophysical Galactic and extragalactic foregrounds. Taken together, LFI and HFI will provide the frequency coverage necessary for an accurate separation of the CMB from foreground emission.

PLANCK will set constraints on the fundamental physics at energies larger than 10^{15} GeV and will produce a wealth of information on the properties of the extragalactic sources and on the dust and gas in our own Galaxy.

The expected scientific output of the PLANCK mission is described in PLANCK Blue Book (PLANCK Collaboration).

The final scientific performance of the PLANCK mission depends not only on the instrumental performances, but also on the detailed knowledge of the behavior of the astrophysical foregrounds and the stringent control of the systematic effects.

2. Instrumental performances, foreground emission and systematic effect control

The CMB anisotropy pattern is a single realization of a stochastic process and therefore it may be different from the average over the ensemble of all possible realizations of the given (true) cosmological model with given parameters. This translates into the fact that the $a_{\ell m}$ coefficients are random variables (possibly following a Gaussian distribution), at a given ℓ, and therefore their variance, C_ℓ, is χ^2 distributed with $2\ell+1$ degrees of freedom. The relative variance δC_ℓ on C_ℓ is equal to $\sqrt{2/(2\ell+1)}$ and is quite relevant at low ℓ. This is the so-called "cosmic variance" which limits the accuracy of the comparison of observations with theoretical predictions. Another similar variance in CMB anisotropy experiments is related to the sky coverage since the detailed CMB anisotropy statistical properties may depend on the considered sky patch. This variance depends on the observed sky fraction, f_{sky}. At multipoles larger than $few \times 10^2$ the most relevant uncertainties are related to the experiment resolution and sensitivity. All these terms contribute to the final uncertainty on the C_ℓ according to Knox (1995):

$$\frac{\delta C_\ell}{C_\ell} = \sqrt{\frac{2}{f_{sky}(2\ell+1)}}\left[1 + \frac{A\sigma^2}{NC_\ell W_\ell}\right], \tag{1}$$

[1] http://astro.estec.esa.nl/Planck.