

## Mapping the ionizing sources with CMB polarization measurements

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With the three-year data, the *Wilkinson Microwave Anisotropy Probe* (WMAP3) produced a more accurate determination of the electron scattering optical depth, downwarding its value from  $\tau_{es} = 0.17 \pm 0.08$  obtained with the first-year data (WMAP1) to  $\tau_{es} = 0.09 \pm 0.03$ . As a consequence, the structure formation in the  $\Lambda$ CDM best fit model obtained WMAP3 is delayed relative to that of WMAP1.

We show that the delay of structure formation can not fully account for the reduction of  $\tau_{es}$  from WMAP1 to WMAP3 when the radiative transfer effects and feedback mechanisms are took into account in computing the reionization history of the Universe.

We also show that a PopIII stellar cluster with a mass of  $80M_{\odot}$  and a heavy Larson initial mass function has an ionizing efficiency high enough to account for WMAP3 results, while in the case of WMAP1, a higher stellar mass of  $1000M_{\odot}$  was required.

As the ultimate limit in constraining the reionization history of the Universe with PLANCK will be placed by the our understanding of systematic effects and foregrounds removal, we discuss also these aspects.

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## 1. Introduction

With the three-year data on the anisotropy of the cosmic microwave background (CMB) and its polarization, the *Wilkinson Microwave Anisotropy Probe* (WMAP3) produced a more accurate determination of the electron scattering optical depth, downarding its value from  $\tau_{es} = 0.17 \pm 0.08$  [1] obtained with the first-year data (WMAP1) to  $\tau_{es} = 0.09 \pm 0.03$  [2, 3], consistent with an abrupt reionization at redshift  $z_{re} \simeq 11$ , significantly later than  $z_{re} \simeq 17$  as implied by WMAP1.

Other most important changes of the cosmological parameters from WMAP1 to WMAP3 are the reduction of the normalization of the power spectrum on large scales ( $\sigma_8 = 0.92 \rightarrow 0.76$ ) and the reduction of the scalar spectral index of the primordial density perturbations ( $n_s = 0.98 \rightarrow 0.74$ ). As a consequence, the structure formation in the  $\Lambda$ CDM model with the primordial power spectrum of the density fluctuation obtained by WMAP3 is delayed relative to that of WMAP1.

Based on the simple assumption of constant ionizing efficiency, a recent paper [4] claims that the delay of structure formation controls the reionization in WMAP3 best fit model such that, if ionizing efficiency is large enough to make reionization early and  $\tau_{es} = 0.17$  in WMAP1 case, the same efficiency is required to have the reionization later and  $\tau_{es} = 0.09$  in WMAP3 case.

In this paper we show that the delay of structure formation can not fully account for the reduction of  $\tau_{es}$  value from WMAP1 to WMAP3 best fit models when the radiative transfer effects and feedback mechanisms are take into account in computing the reionization history of the Universe. We also show that a PopIII stellar cluster with a mass of  $\sim 80M_\odot$  and a heavy Larson IMF has an ionizing efficiency high enough to account for the or the value of  $\tau_{es}$  obtained by WMAP3.

PLANCK surveyor will have enough sensitivity the test various reionization models even when they imply the same value for  $\tau_{es}$  [6].

As the ultimate limit in constraining the reionization history of the Universe with PLANCK will be placed by the our understanding of systematic effects and foregrounds removal, we discuss also these aspects.

## 2. WMAP 3-year data: implications for the properties of ionizing sources

We compute the reionization histories of the Universe for the emission of a PopIII stellar cluster of mass  $M$  and a heavy Larson IMF for different values of the parameters ( $n_s, \sigma_8, M$ ). Our computation includes all the radiative mechanisms relevant for the primordial gas dynamics: photo-ionization, photo-heating and cooling of the hydrogen and helium in the expanding Universe. The mean UVB flux is obtained as solution to the radiative transfer equation by assuming a constant star formation efficiency  $f_* = 0.1$ . The details of the computation can be found in [5].

The model parameters and the corresponding values of  $\tau_{es}$  are given in Table 1. The model WMAP\* was constructed to have the same values for  $n_s$  and  $\sigma_8$  as WMAP1 and the same stellar mass as WMAP3.

We find that a stellar cluster with a mass of  $M \simeq 80M_\odot$  has an ionizing efficiency high enough to account for WMAP3 value of  $\tau_{es}$  while for the case of WMAP1 a higher stellar mass,  $M \simeq 1000M_\odot$ , is needed. For WMAP\* model we obtain a value of the electron optical depth of  $\simeq 0.13$  that can account for about 80% from that obtained by WMAP1.

Model	$n_s$	$\sigma_8$	$M/M_\odot$	$\tau_{es}$
WMAP1	$0.99\pm 0.04$	$0.92\pm 0.1$	1000	$0.157\pm 0.032$
WMAP3	$0.961\pm 0.017$	$0.76\pm 0.05$	80	$0.093\pm 0.012$
WMAP*	$0.99\pm 0.04$	$0.92\pm 0.1$	80	$0.130\pm 0.032$

**Table 1:** Model parameters

On the basis of these calculations, we conclude that, although WMAP3 has not enough sensitivity to constrain the reionization history [3], the delay of structure formation in WMAP3 best fit model can not fully account for the reduction of  $\tau_{es}$  from WMAP1 to WMAP3 when the radiative effects and feedback mechanisms are take into account.

### 3. Perspectives from the PLANCK mission: sensitivity and systematic effect control

A fundamental aspect in constraining the reionization history with PLANCK CMB measurements, which is necessary to fully exploit its increasing sensitivity, is the accurate control of all systematic effects, of instrumental and astrophysical origin and of their interplay. From the point of view of the angular power spectrum recovery, an useful classification of systematic effects can be based on their different relevance at different multipoles.

Sidelobe pickup from Galactic emission and CMB dipole [7, 8] will mainly affect the low multipole region from  $\sim$  the dipole scale to  $\sim$  the first acoustic peak (in the possible presence of bad optical behaviours and depending also on the scanning strategy the straylight from inner Solar System bodies could also affect the data). These effects can be accurately removed (for example through iterative methods) during data analysis only in the presence of a very accurate understanding of the instrument optical properties in work conditions.

Main beam distortions [9, 10] mainly affect the highest multipole region accessible to the resolution of a given receiver, i.e. the multipoles region of secondary acoustic peaks. Again, the removal of this effect based on the accurate evaluation of the effective window function (because of the coupling between beam window function and scanning strategy) or on deconvolution codes requires a very accurate knowledge of the main beam shape, possible in flight using the transit on the main beam of external planets (or, in general, of bright, stable, and point-like sources). Pointing errors could also affect particularly the high multipole region, but this problem has been largely reduced in the PLANCK mission by the use of high precision (up to few arcseconds) star trackers.

Non-idealities in LFI radiometers and bolometers introduce  $1/f$ -like noise while long term drifts can be also induced by temperature instability [11, 12]. These effects have impact at both low and high multipoles because of the stripes induced in the maps. Dedicated destriping and map-making methods have been implemented and tested to reduce their effect in the map and in the angular power spectrum. [13, 14]. Only a largely reduced excess of power at low multipoles (because of noise long term correlation) is the most remarkable effect remaining after data reduction, that can be properly modelled through simulations.

Since LFI and HFI could in principle have different responses to the various systematic effects, a powerful tool for the detection and reduction of systematic effects in the PLANCK data will derive also from the accurate comparison between the data at the closest frequencies of LFI and HFI, respectively the 70 GHz and 100 GHz channels, where also foreground contamination is expected to be almost minimal.

In general, the PLANCK goal is the achieve a suppression of any systematic effect at a level better

than  $\simeq 3\mu\text{K}$  ( $\simeq 1\mu\text{K}$ ) in terms of peak-to-peak (RMS) spurious signal.

The control of systematic effects and the wide frequency coverage of PLANCK, allowing an accurate modelling and removal of foregrounds, will make this mission almost limited only by cosmic variance, at least for total power data. For polarization measurements, the situation is probably more complicated because of the intrinsic weakness of CMB polarization anisotropy, the increasing of complexity in systematic effect control and subtraction, and finally, the largest relative weight of polarized foregrounds that need to be understood and removed at few percent accuracy level, or better, for an accurate study of CMB polarization anisotropy.

On the other hand, at least for the  $E$  mode, PLANCK is expected to reach an accuracy level sufficient not only to precisely measure the Thomson scattering optical depth but also to constrain among various possible cosmological reionization histories [6].

## References

- [1] D.N. Spergel et al., *First-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Determination of Cosmological Parameters*, *ApJs* **148** (175) 003
- [2] L. Page, et al., *Three Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Polarization Analysis*, *ApJ* (submitted) 006 [astro-ph/0603450]
- [3] D.N. Spergel et al., *Wilkinson Microwave Anisotropy Probe (WMAP) Three Year Results: Implications for Cosmology*, *ApJ* (submitted) 006 [astro-ph/0603449]
- [4] M.A. Alvarez, P.R. Shapiro, K. Ahn, I.T. Iliev, *Implications of WMAP Three Year Data for Reionization*, 006 [astro-ph/0604447]
- [5] L.A. Popa, *WMAP 3-year polarization data: Implications for the reionization history*, 006 [astro-ph/0605358]
- [6] L.A. Popa, C. Burigana, N. Mandolesi *Radiative effects by high- $z$  UV radiation background: Implications for the future CMB polarization measurements*, *N.A.* **147** (175) 005
- [7] C. Burigana et al., *Trade-off between angular resolution and straylight contamination in the PLANCK Low Frequency Instrument. II. Straylight evaluation* *A&A* **428**, 311, 04
- [8] A. Gruppuso, C. Burigana, F. Finelli, *Dipole straylight contamination and low multipoles*, (this conference)
- [9] C. Burigana et al., *Beam distortion effects on anisotropy measurements of the cosmic microwave background* *A &As* **130**, 551, 998
- [10] N. Mandolesi et al., *On the performance of Planck-like telescopes versus mirror aperture*, *A & As* **145**, 323, 000
- [11] M. Seiffert et al., *1/f noise and other systematic effects in the Planck-LFI radiometers* *A & A* **391**, 1185, 002
- [12] A. Mennella et al., *PLANCK: Systematic effects induced by periodic fluctuations of arbitrary shape*, *A&A* **384**, 736, 002
- [13] D. Maino, *The Planck-LFI instrument: Analysis of the 1/f noise and implications for the scanning strategy*, *A&As* **140**, 383, 999
- [14] G. de Gasperis et al., *ROMA: A map-making algorithm for polarised CMB data sets*, *A & A* **436**, 1159, 005