<u>**Polarisation of the Cosmic Microwave Background**</u>

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Introduction: Cosmology is presently a very active field because of the large number of observations that are becoming available and that will allow us to characterize with great precision the nature and physical origin of the primordial cosmological perturbations, as well as of dark matter and dark energy.

The first objective consists in developing and implementing a novel estimator of the primary polarisation signal of the cosmic microwave background (CMB). This signal can be measured from the gravitational lensing field to be extracted from CMB maps. This type of analysis will be particularly important in the sequence of the public release of CMB polarisation data by the Planck Collaboration (due beginning of 2014) and in the context of the tasks of the CMB Cross-Correlations Science Working Group of the Euclid Consortium.

The second objective consists in assessing the robustness of the estimator of the primary CMB with respect to contamination by secondary CMB polarisation effects, which is not being considered in the current CMB data analysis. This requires the development of a detailed model of the secondary polarisation signals, such as the CMB quadrupole and double-scattering induced polarisations, which act as contaminants in the detection of the primary signal. This topic is related to the detection of CMB secondary polarisation by galaxy clusters with the ALMA interferometer.

Description: The CMB radiation is supposed to originate from the last scattering surface (the time when radiation decoupled from matter) and to have propagated almost unperturbed until today. The CMB is a unique source of information about the physics of the primordial Universe and its subsequent evolution. In particular, the CMB polarisation (Hu & Dodelson 2011, Aghanim et al. 2011) is becoming a key observational tool for cosmology and large scale structure formation studies. It allows to probe the early universe and to tighten constraints and/or break degeneracies on cosmological parameters (Planck collaboration 2003 XVI, XXIII). Whereas the temperature maps produce by Planck have already been extensively analysed, the polarisation analysis has been postponed to the next series of papers.

1st Objective: Primary polarisation induced by CMB lensing

Photons travelling along the line of sight between the last scattering surface and an observer today were deflected by intervening dark matter distribution by means of gravitational lensing. This process conserves surface brightness and polarisation; consequently it does not generate fluctuations in the temperature or polarisation of the CMB, but instead smoothes them and shifts them to smaller scales. This process distorts the temperature-temperature (TT) correlation power spectrum coherently over scales of 2 arcmin. It also mixes and distorts the EE and BB polarisation power spectra (Seljak 1996).

The relevance of the CMB lensing reconstruction for cosmology is twofold.

By distorting the E-mode polarisation, the CMB lensing induces a B-mode polarisation which is a major contaminant in the measurement of the primordial B-mode polarisation predicted by some inflationary models. CMB lensing is also a powerful cosmological probe of the matter distribution integrated from the last scattering surface to the present time. Thus, *delensing* the CMB will allow to recover the primordial B-mode and probe the full-sky large scale structure distribution with a maximum efficiency at z~3 (Lewis & Challinor 2006), thus having the potential to distinguish among models of gravity (Sherwin et al. 2011).

Effort has been devoted to developing an optimal reconstruction of the lensing potential in harmonic space, which implicitly assumes full-sky, coverage without cuts or uneven sky coverage. For a reconstruction based on the temperature anisotropy alone, it bas been shown how to construct an optimal quadratic estimator in this idealized context (Okamoto and Hu 2003). For the exploitation of polarised anisotropies, at a high sensitivity where the B signal is entirely due to lensing, the quadratic estimator underperforms and the higher-order corrections to the quadratic estimator present in the maximum likelihood estimator are no longer negligible (Hirata & Seljak 2003).

Since weak lensing is manifested essentially at very small scales, all the information relevant to lensing reconstruction lies on angular scales close to the resolution scale of the sky map. As an alternative to the conventional harmonic-space estimator (Wu 2001), an estimator has been proposed (Carvalho & Moodley 2010) that is slightly less optimal and modified to have a finite range and a kernel in real space. The prospective candidate will extend the implementation of the real-space estimator to the CMB polarisation in order to optimize the extraction of the lensing information from high-precision CBM polarisation maps.

2nd Objective: Secondary polarisation induced by galaxy clusters and filaments

In addition to the primary CMB polarisation, signals arising from secondary polarisation effects significantly contribute to the observed polarisation. In particular the scattering of CMB photons by reionized (mostly primordial) gas produces polarised radiation, which carries invaluable information about the scattering medium as well as the primordial CMB signal. Among the strongest effects are: a) the polarisation induced by the CMB quadrupole (which couples the primary CMB quadrupole anisotropy to the electron density fluctuations of the reionized gas), b) the transverse-motion induced polarisation (which is related to the transverse motion of the gas cloud), c) the double-scattering polarisation (due to an induced anisotropy at the second scattering event) and d) the Faraday rotation polarisation (which arises in the presence of magnetic fields). Although preliminary studies exist on some of these effects (e.g. Ramos et al. 2012, Liu et al. 2005 and references therein), a thorough characterization of the aforementioned polarisation signals is presently missing while it is crucial for the preparation and exploitation of high-precision CMB observations, such as those of Planck, ALMA and the future PRISM satellite.

The prospective candidate will engage in this characterization using state-of-the-art numerical simulation methods and will apply them to existing tools (e.g. the Planck Sky Model) that are used within international consortia, such as Planck and PRISM, to predict survey yields and test methods to maximise the scientific return from polarisation observations. Emphasis will be given to the detection of secondary polarisation in galaxy clusters with the ALMA interferometer. An important part of the work will be focused on the separation between primordial and secondary polarisation components, and in assessing the constraining power of the different types of polarisation information on cosmological and structure formation parameters. An interesting extension of this work is the development of methods for the separation of the different polarisation components at the ALMA frequencies.

This proposal aims to work on a key issue of observational cosmology in order to provide tools that meet the unprecedented level of significance and accuracy required by PLANCK and forthcoming probes such as PRISM, for a successful treatment and interpretation of the new data sets.
In particular, we propose the student to:

- extend the implementation of the real space estimator to the CMB polarisation.
- model contaminants of the CMB polarisation signal so as to extract the primary signal.
- analyse the cosmological implications and constrain gravity theories with weak lensing.