

Planck satellite constraints on Particle Physics with the measurements of Cosmic Microwave Background anisotropies

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The PLANCK satellite is an ESA mission due to be launched in 2008. It will provide an essentially complete view of the CMB anisotropies limited only by the cosmic variance. The global parameters of the Universe will then be determined with a percent level precision. They include the geometry and evolution of the Universe as well as the relative proportion of the cosmic components, dark energy, dark matter, baryonic matter, neutrinos, photons. . . An accurate measurement of the polarization of these anisotropies should enable us to determine a precise reionization history as well as some constraints on the mass of neutrinos and on the primordial gravitational wave background, a telltale of the inflationary paradigm. Flight models of the two instruments (HFI and LFI) on board PLANCK are being actively calibrated on-ground before the final satellite integration at the end of 2006. Expected and measured performances are addressed. Efforts are pursued on the processing pipeline assembly. (see also <http://www.rssd.esa.int/Planck>)

1. THE COSMIC MICROWAVE BACKGROUND ANISOTROPIES

The measurement of anisotropies of the cosmic microwave background (CMB) is one of the fundamental assets in our era of precision cosmology. Two basic reasons are that the anisotropies dominate the sky in the millimetre and decimetre radio domain, outside the galactic plane and that the predictions of the CMB angular correlation function are robust calculations (a regime of linear perturbations in a not-so-hot plasma at 3000 K). A dozen cosmological parameters can thus be constrained such as the curvature parameter, the Hubble constant, the cosmological constant, the total matter content, the baryonic content. . . The CMB anisotropies are also used to set up the initial conditions for structure formation under the general scenario of gravitational collapse.

Great advances in CMB anisotropy measurements have been achieved with ground-based, balloon experiments, and the all-sky radio survey

made by the WMAP satellite [3]. The precision on cosmological parameters is now of the order of 5 % if one makes simple hypotheses on the inflation-based Big Bang scenario. Spergel *et al.* [8] summarizes the WMAP measurement of the cosmological parameters. The Universe is flat within 2 %. It is dominated by the so-called dark energy, the reduced density value (*i.e.* divided by the present critical density) being 0.75 ± 0.04 , with an equation of state of $w = p/\rho = -0.98 \pm 0.08$ when joint-analyzed with the Supernova Legacy Survey [2]. This dark energy is fully compatible with a cosmological constant. We thus live at the start of a second inflationary phase of the Universe. Baryonic matter makes only 0.042 ± 0.002 a small fraction of the total matter 0.24 ± 0.02 . Therefore, the matter content of the Universe is dominated by some form of dark matter made of unknown particles (beyond the Standard Model of Particle Physics). They are mostly cold (non-relativistic at the radiation-matter transition) and have almost no interaction with the usual matter that makes up stars and the visible part of galaxies.

PLANCK is a whole sky survey, designed to be the ultimate experiment in CMB anisotropy measurement in the sense that most of the information in the CMB anisotropies will be gathered, limited only by the cosmic variance, *i.e.* the fact that we measure only one realization (the 4π sky) of a random process. The general scientific description of PLANCK is given by [7]. In particular the increase of sensitivity by at least a factor 10 and the improvement in resolution by a factor 3 with respect to WMAP should allow a detection of up to the 7th acoustic peak [9] in the angular power spectrum of temperature anisotropies. This increases the leverage in ℓ space and thus greatly improves the measurement of the initial perturbation power spectrum. Control of foregrounds is ensured by the wide spectral range covered by the 9 bands of the two instruments LFI (30 to 70 GHz) and HFI (100 to 857 GHz) and sophisticated processing component separation methods. Polarization measurements will be done for seven of these bands. Control of systematics (e.g. careful optical baffling to avoid far sidelobes) have been introduced early in the hardware design and will be evaluated during the data processing. Gain in sensitivity is obtained, via a complex cryogenic chain, by cool 20 K radiometer using High Electron Mobility Transistor (HEMT) amplifiers for LFI, and cold 100 mK state-of-the-art bolometers for HFI. The gain in angular resolution comes from the high frequencies.

2. CONSTRAINTS ON PARTICLE PHYSICS FROM PLANCK

We briefly illustrate here the close connection between the PLANCK cosmological space experiment and Particle Physics.

Inflation predicts a near scale invariance spectrum of the primordial fluctuations that lead to structure formation from gravitational collapse. PLANCK through its increase ℓ range coverage, should set percent precision on the power law exponent.

The primordial Universe allows particle physicists to test the standard model at energies much higher than Earth particle accelerators can produce. In particular, the physics of the inflation

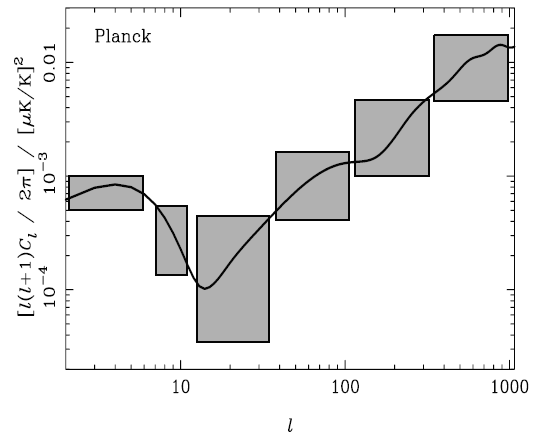


Figure 1. The B-mode constraints (one- σ boxes) expected from PLANCK. A primordial gravitational wave background generates some odd-parity polarization modes in the CMB anisotropies (continuous curve). These B-modes are much weaker than the E-modes generated at the epoch of decoupling of matter from radiation. However, the Compton interaction at the origin of the CMB polarization cannot produce B-modes from scalar fluctuations. At low ℓ multipole B-modes are a unique signature of inflation, here drawn for a tensor to scalar fluctuation ratio of 10%, equivalent to an energy scale of inflation of 2×10^{16} GeV. High ℓ (> 100) B-modes are foregrounds created from weak lensing of E-modes by background structures.

era can be tested with PLANCK. If inflation happens at GUT scales [1], then a detectable background of gravitational waves might have been generated. PLANCK can give constraints on this background via the B-mode CMB polarization spectrum (Fig. 1).

Neutrino mass can also be constrained. Oscillation experiments are only sensitive to square mass difference between the different neutrinos, whereas CMB experiments are sensitive to the total mass of the neutrinos which constitute the only known hot dark matter component. Indeed, although a sub-dominant component of matter

in the Universe, massive neutrinos cluster on large scales while their free-streaming, when they were still relativistic, can erase small-scale fluctuations. Several calculations [5,6,4] show that PLANCK can set strong limits on the mass of neutrinos at the $\Sigma m_\nu \sim 0.07 - 0.25$ eV level.

Finally dark energy can be measured via several effects. For example, the number counts of Sunyaev-Zel'dovich effect clusters of galaxies depend only on the total matter content. For a flat Universe, a measurement of the dark energy is obtained independently of primordial anisotropy constraints but with the same PLANCK experiment.

3. STATUS OF PLANCK

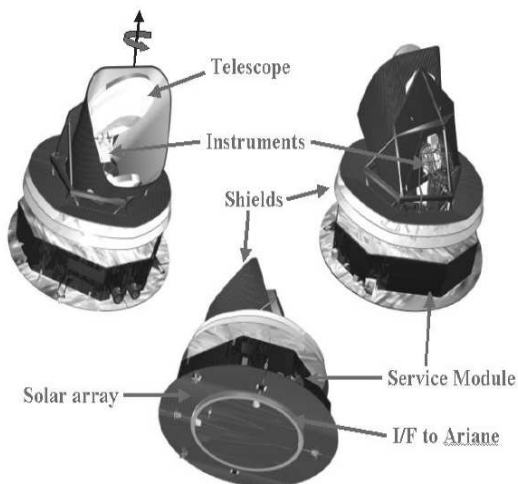


Figure 2. Overview of the PLANCK Satellite. The spin axis points near the antisolar direction. Hence the off-axis Gregorian telescope sweeps an almost big circle of the sky nearly orthogonal to the satellite-Sun axis. The telescope and instruments are passively cooled by 3 V-grooves (the disks above the service module) to below 50 K.

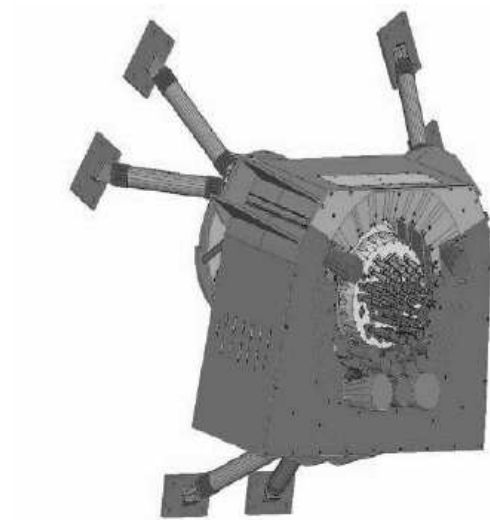


Figure 3. Overview of the PLANCK instruments at the focal plane of the telescope. Horns couple the sky as seen by the telescope into the detectors. HFI 36 horns cover the center of the focal plane whereas LFI 11 horns occupy the outskirts.

3.1. Cooling

The passive cooling main agent comes from V-grooves (Fig. 2). These have been tested in the vacuum at Centre Spatial de Liège (CSL, Belgium). They provide a comfortable temperature below 60 K.

The PLANCK Flight Model (FM) Service Module has been successfully integrated and tested, thereby validating the operation and performances of the hydrogen sorption coolers, cooling the focal plane from 60 K down to 20 K.

The 4 K cooler provides a reference temperature for LFI modulation scheme and another thermal stage for HFI. The 4 K cooler development problems have been solved. Actually, nominal operations will be rather at around 5 K, without impeding the open loop continuous $^3\text{He} - ^4\text{He}$ dilution fridge that produces the HFI 100 mK stage.

Integration of LFI and HFI FM (Fig. 4) is complete and cryogenic tests are under way.

The HFI dilution cooler has successfully reached 85 mK, during several campaigns in different conditions, and for several continuous weeks.

LFI is built by an Italian-led international consortium and HFI is built by a French-led international consortium.

3.2. Performances

All tests so far indicate that the performances of HFI meet the goal specifications whereas LFI is comfortably better than the requirements at all frequencies. Cryogenic tests of the telescope are on-going. The one σ aggregated sensitivity of Planck over the whole sky can be given as $\Delta T_{\text{CMB}} = 3 \mu\text{K}$ for a square average pixel of size 10 arcminutes and twice that number for Q or U Stokes parameter polarization measurements. This sensitivity and control of systematics will improve if the nominal survey of 14 months made of two full skies can be extended, as we can expect from the margins in cryogenic fluids. Angular resolution is set by the diffraction limit of the underilluminated 1.5 m telescope for frequencies below 217 GHz and 5 arcmin Full Width at Half Maximum for the 217 GHz channels and higher frequencies.

3.3. Launch and Survey

PLANCK and HERSCHEL (the ESA submillimetre observatory cornerstone) are to be launched together at Kourou (French Guiana) by the same Ariane 5-ECA rocket. They are then separated half an hour later and they go separately to two different L2 orbits. However, a number of development problems in both experiments have caused unavoidable delays in the launch date. Recently it has become clear that HERSCHEL and PLANCK can be launched in February, 2008. These two missions are quite complementary to dig deep into the last unexplored frequency domain in the electromagnetic spectrum. While PLANCK will provide an all-sky moderate resolution survey in the millimetre and submillimetre domain (the main legacy after the cosmology), HERSCHEL will make deep but narrow surveys with higher angular resolution in the far-infrared and submillimetre domains.

After cruising to its L2 orbit in 4 months,

PLANCK will be actively calibrated during 2 months and the sky surveys can start (1–2 years). After one year of data processing and one year of proprietary period, during which the most important results should be published by the PLANCK Consortium, data will be made public for the whole community, typically around 2012–2013.

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Figure 4. Integration of the 4 K HFI Back-to-Back horns. Each horn couples the telescope to one detector assembly. Note the curvature of the focal plane (top of the back-to-back horns) due to the chosen off-axis Gregorian PLANCK telescope.