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The Flexible Planck Scanning Strategy

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Abstract. A key issue for the success of the PLANCK ESA mission is the planning of a proper scanning strategy able to ensure a good sky coverage and optimal instrument operations. The scanning strategy is characterized by the way in which the telescope will scan the sky. Repointing manoeuvres will allow a complete mapping of the sky in about six-seven months. Different scanning strategies deal with the rate of repointing manoeuvres and the long term motion of the spin axis. We present here some of the main aspects and of the most relevant results of recent analyses aimed at defining the PLANCK baseline scanning strategy.

Key words. Cosmology: diffuse radiation, cosmic microwave background – Space vehicles: instruments.

1. Introduction

The ESA PLANCK satellite[1], scheduled for launch in 2007, represents the third-generation of space missions dedicated to the cosmic microwave background (CMB) and millimetric (mm) and sub-mm astronomy after COBE and WMAP by NASA. Two instruments at the focus of the PLANCK 1.5 m Gregorian aplanatic telescope will cover the frequency bands 30, 44, and 70 GHz - *Low Frequency Instrument*, LFI - and 100, 143, 217, 353, 545, and 857 GHz - *High Frequency Instrument*, HFI. A key issue for the success of the PLANCK ESA mission is the planning of a proper scanning strategy (SS) able to ensure a good sky coverage (Dupac & Tauber 2005), thermal stability, and proper telecommunications, and to reject systematic effects, such as straylight effects. The SS is characterised by the way in which the telescope will scan the sky while PLANCK will describe its Lissajous orbit around the Lagrangian L2 libration point of the Sun-Earth system. The satellite will spin at a rate of about 1 r.p.m. around its spin axis. The telescope line of view is kept at an angle of 85° with respect to the spin axis. Nearly great circles will then be observed by PLANCK. Small differences in the scanning path will occur for different feed horns, owing to their different locations on the telescope focal plane. Hourly repointing manoeuvres will shift the spin axis of a nominally constant angle, allowing a complete mapping of the sky in about six-seven months. Different SSs deal with the rate of re-

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[1] http://rssd.esa.int/Planck

pointing manoeuvres and the long term motion of the spin axis. Accurate analyses on the SSs possible for Planck aimed at defining an optimal baseline are in progress within the Planck collaboration. We present here some of the main aspects and of the most relevant results, focusing in particular on SSs with and without slow precessions of the spin axis around the Sun-spacecraft direction.

2. Scanning law optimization

Polar Holes and Deep Fields. Given the spacecraft and telescope configuration and except for minor phase displacements along each scan circle, the Planck SS is fully defined by the set of the spin axis pointing directions during the mission lifetime. A non perfectly uniform distribution of the sensitivity per pixel in the sky is unavoidable for Planck. In the *nominal* SS, the spin axis is kept rigorously in the antisolar direction, i.e. in practice almost parallel to the ecliptic plane. This simple scheme allows to simplify the data processing and spacecraft operations. In the *precessed* SS the spin axis slowly precesses with a period, P, of about 6 months with a constant precession amplitude of at most 10°. Ground and space operations are partially more complicated in this scheme. In both cases the repointing is applied in discrete steps along the ecliptic of about $2.5'$ every hour so that Planck will scan about 60 times the same nearly-great circle between successive repointings by keeping the Solar aspect angle constant.

The sensitivity per pixel approximately scales with the colatitude, θ, as $\sqrt{\sin\theta}$ over most of the sky (this approximation being particularly good for the nominal SS), except close to the ecliptic poles where a better sensitivity is obtained because of the pile-up of the scan circles that produces two polar deep fields (DF). Since the different locations of the feed-horns within the focal plane, each feedhorn will have a different distribution of sensitivities over the sky, particularly near the poles. In the case of the nominal SS, each polar DF is a ring at angular distance from the pole, d, of $\sim 5^\circ$; the exact value of d and the angular size of the ring depend on the considered receiver and on the adopted ratio, r, between the sensitivity in the less observed pixel of the polar DF and the sensitivity averaged over the whole sky. The main disadvantage of this SS is the presence of an unobserved region inside the DF ring and of a corresponding high sensitivity gradient. Precessed SSs have the advantage of avoiding the presence of the inner unobserved regions and better fill the polar DF and distribute the sensitivity around the DF. This is important in particular for DFs shared by different feed horns, allowing detailed multifrequency analyses of these regions whose detailed positions could be possibly optimized to have a minimal foreground contamination. In both cases, for $r \sim 2$ the solid angle of each DF is ~ 300 deg^2.

Straylight. Straylight contamination from the Galaxy turns out to be largely independent of the SS (Burigana et al. 2001). The rejection of the straylight contamination from inner Solar System bodies (only Sun, Earth, and Moon are relevant in practice) largely depends on the level of the beam response in the corresponding beam sidelobes. With detailed simulations we addressed the implications of different SSs. A precessed SS may slightly reduce the impact of Earth and Moon straylight contamination but it substantially increases the impact of the Sun straylight contamination, because of the larger beam region where the Sun light enters. When expressed in terms of angular power spectrum, the Moon and Earth straylight contamination is predicted to be well below the CMB signal, the cosmic variance, and the noise level, essentially independently of the considered SS. The same is found for the Sun for the nominal SS, while for the case of the precessed SS this is true only provided that the beam response in the relevant beam region does not exceed a value (for example ~ -100 dB at 70 GHz – beam normalized to the maximum) significantly weaker than that able to assure a negligible Sun straylight contamination for the nominal SS. A more stringent control of this systematic effect is then required for the precessed SS.

Telemetry Constraints. Reliable contact for telemetry down-links with full bandwidth is ensured only if the Earth is seen by the *High*

Gain Antenna (HGA), located at the bottom of the spacecraft, and is aligned in opposition to the spin-axis, within 15° from its pointing direction. The HGA-Earth angle, α, is a function of the spacecraft position and the pointing direction. In the nominal SS α is always $< 15°$, but the limit angle is approached near the extremes of the PLANCK Lissajous orbit. Therefore, any displacement of the spin axis from its nominal position has to be checked with respect to the telemetry constraint and may be critical (with relevant implications for the last topic discussed in this work). This problem can be significantly alleviated in the case of the precessed SS by taking advantage of the possibility to properly synchronize the spacecraft Lissajous orbit and the spin axis precession with a suitable choice of the initial position of the spin axis, of the sense of the spin axis rotation along the precession cone, and, of course of the precession period ($P \simeq$ 6 months is always appropriate). In fact, they are not free parameters: only the appropriate sense of the spin axis rotation along the precession cone and a limited range of initial spin axis positions, possibly tuned to optimize also the day-by-day calibration with dipole, can ensure the telemetry requirements during the survey (Cappellini et al. 2005).

Thermal Effects. A spin axis precession seasonally changes the aspect angle of the spacecraft with respect to the Sun. It leads to potential seasonal variations in the heat balance of the spacecraft *Service Module* (SVM) and changes the dissipation efficiency of radiators of the active cooling system. A change in the heath balance between the incoming solar radiation and the spacecraft thermal dissipation will result in changes in the system temperature leading to changes in the noise properties, as a drift in the zero point of the detectors. Accurate simulations of these effects require a dedicated software capable to handle both the radiative and conductive aspects of the thermal model and are in progress. Thermal effects are kept under control ensuring that: *i*) the Sun aspect angle is kept within 10° to prevent direct solar irradiation of thermal radiators or any optical part; *ii*) the Sun aspect angle is kept as constant as possible; *iii*) no parts inducing significant shadows are left on the bottom of the spacecraft. With these prescriptions, long-term thermal instabilities due to the SS shall be smaller than those induced by the 7% variation of the radiation flux due to the time dependence of the spacecraft-Sun distance due to the Earth orbit ellipticity.

Recovery of Badly Observed Sky Regions. Occasionally, it is possible that some small gaps will be introduced in the survey due to telecommunication problems with the ground segment or maintenance operations (Maino et al. 2003). In addition, the active cooling system will have to be stopped during the mission in order to switch from the main cooling unit to the backup unit to allow regeneration of the main cooling units which otherwise would become less performant. During switch-over, data acquisition will be stopped, or at least perturbed, significantly increasing the noise. Consequently, the SS will have to be flexible enough to allow a satisfactory recovery of the sky regions lost or badly observed because of such problems.

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