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Radiosource observations with the PLANCK satellite

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Abstract. The PLANCK satellite, devoted to the study of the cosmic microwave background primary anisotropies, will produce full sky surveys between 30 and 900 GHz. Millimetre wavelength channels will provide useful data for the study of radiosources. Current models, supported by WMAP results, predict the observation of some thousands of sources for which spectral informations in a frequency range currently poorly explored will be obtained. We present here the sensitivity of the PLANCK channels for this kind of measurements and the impact of some systematic effects in the source flux recovery. We discuss the PLANCK capability in reconstructing source variability at different timescales.

Key words. Radiosources, variability – cosmic microwave background – space missions

1. Introduction

The PLANCK satellite by ESA[1] is designed and optimized to measure primary anisotropies of the cosmic microwave background (CMB) (see Burigana et al., and Finelli et al.*this issue*). The images that it will produce from 30 to 857 GHz will have an unprecedented combination of sky coverage, calibration accuracy, freedom from systematic errors, stability, and sensitivity.

Data produced by the two on–board instruments, the Low Frequency Instrument (LFI, Mandolesi et al. 1998; see Sandri et al.*this issue*) and the High Frequency Instrument (HFI, Lamarre et al. 2003), will represent also a good opportunity to study the astrophysics of extragalactic radiosources. This analysis will be carried out by exploiting both maps and Time Ordered Data (TOD). While the analysis of maps, taking advantage from repeated sky observations, can reach lower average fluxes (Vielva et al. 2003 2000), the analysis of TOD to study the source time variability is necessarily limited to the brightest sources. Nevertheless, PLANCK may be expected to observe a number of extragalactic flaring sources, particularly blazars or extreme GHz Peaked Spectrum (GPS) sources, and of Galactic micro-blazars. We exploit the 30, 44 and 70 GHz LFI channels and the 100 and 143

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

GHz HFI channels, which are the most sensitive to radiosources. In the first section, we describe our method to perform the flux extraction taking into account the instrumental features and scanning strategy and show results about sensitivity in source flux measurement. In the second section, the impact of systematics on this kind of measurements is discussed. Finally, some results regarding the simulation of source spectra and lightcurves measurements are shown in last section.

2. Source flux extraction

A set of simulations was performed in order to evaluate and optimize the source flux recovery with PLANCK. Taking into account instrumental properties and the satellite scanning strategy, TOD were produced for sources at different locations in the sky. Due to the relevant ecliptic latitude sensitivity dependence (see Fig. 1), three main sources were studied, at low, medium and high ecliptic latitudes. The sensitivity, normalized to the average sensitivity, as a function of the ecliptic colatitude is close to unity at ecliptic colatitudes $\theta_e \simeq 50°$ and 130° and it is quite well approximated by the law $\sqrt{\sin\theta_e/\sin 50°}$.

Once the TOD are derived the set of data regarding the source transit are extracted and the flux is evaluated inverting the relation antenna temperature–flux, as:

$$\left(\frac{F}{\mathrm{Jy}}\right) \simeq 2.95 \cdot 10^{-3} \left(\frac{\mathrm{FWHM}}{\mathrm{arcmin}}\right)^2 \left(\frac{\nu}{\mathrm{GHz}}\right)^2 \frac{1}{J} \left(\frac{T^{ant}}{\mathrm{K}}\right), \tag{1}$$

where J is the beam response normalized to the maximum response. In this way we can produce an array of fluxes whose mean value is the flux estimation. As evident in Fig. 2, when data are too far from the beam center, the noise is the dominant component, so that an appropriate collection of measures have to be used in order to have enough data to be averaged but in the correct range around the source peak.

The optimal range of data, to be used for the flux extraction, has been estimated applying 1000 different noise figures to the source TOD for each frequency channel and considering different source locations. Some representative results are shown in Tab. 1. The optimal range, where relative error in flux recovery is minimized, is about one FWHM around the source peak for almost all the frequency channels. This holds both for the scan circle direction and for the spin axis repointing direction (in the latter case the relevant (azimuthal)

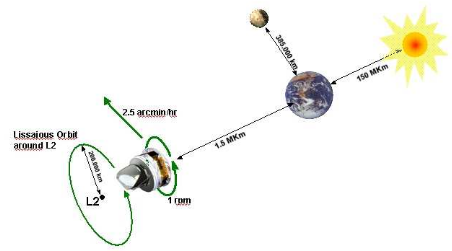

Fig. 1. The beams will scan 60 times per hour the same circle in the sky ($\simeq 85^o$ from spin axis) and then the spin axis will move of 2.5’ on the ecliptic equator and another scan circle is observed. This leads to an integration time depending on the ecliptic latitude of the observed region. As an example, the source transit through the beams will occur in about a week (20 days) for sources on the ecliptic equator (at about 70^o ecliptic latitude).

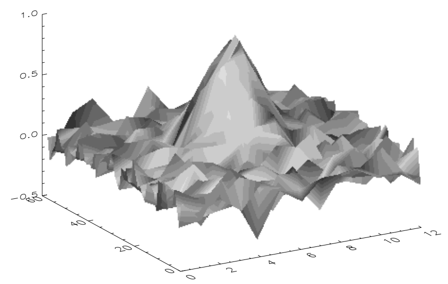

Fig. 2. TOD (antenna temperature in mK) of a 3 Jy source transit across 30 GHz beam. Far from the beam center (x step is 2.5’, y step is 10’) the noise dominates and the source flux recovery is no longer accurate.

Table 1. Planck sensitivity to the flux recovery for a bright source at low ecliptic latitudes by considering a single feed (or beam) at each frequency.

ν GHz	$\Delta F/F$ 1 Jy	$\Delta\phi_{eff}$ (FWHM)	$\Delta F/F$ 5 Jy	$\Delta\phi_{eff}$ (FWHM)
30	0.076	1.0–1.2	0.016	1.0–1.2
44	0.120	1.1	0.026	1.0–1.3
70	0.239	1.0	0.056	1.1
100	0.093	0.8–1.0	0.018	0.8–1.2
143	0.078	1.0	0.016	1.0

spin axis displacement is quoted in terms of $\Delta\phi_{\rm eff} = \Delta\phi \cdot \sin\theta_e$). As expected a better sensitivity is found for sources at an ecliptic latitude of about 65°, because of the longer integration time.

3. Impact of systematics

A further analysis was performed to evaluate the impact of pointing uncertainty and $1/f$ noise on source flux reconstruction.
We applied a random pointing error (one arcmin rms, which is twice the Planck pointing accuracy requirement) and evaluated the resulting relative error in flux recovery (Tab. 2). High frequency channels with a narrow beam are more affected by pointing uncertainty. An additional error derives from the propagation of the pointing uncertainty into the main beam in-flight recovery (Burigana et al. 2002 2000), and then into the source flux recovery. The relative error due to this effect is of about 0.007 and 0.015 (0.022 and 0.044) at 30 GHz (100 GHz) for samples centered respectively at $1\sigma_{beam}$ and $2\sigma_{beam}$ from the source direction.

Results of simulated measurements of a 1 Jy source, before and after the application of a destriping algorithm to four different $1/f$ noise figures (knee frequency 0.1 Hz, 30 GHz channel), show how destriping allows a better flux recovery. A systematic error is found of about 20 – 30% in the flux recovery if the $1/f$ noise drifts are not previously reduced. It significantly decreases (to some %, or less) if the TODs are previously cleaned by applying destriping codes (Maino et al. 1999 2000).

Table 2. Impact of pointing uncertainty ($1'$ at 1σ level) on the source flux reconstruction by considering a single beam (or feed) at each frequency.

ν (GHz)	$\Delta F/F$ (LEL)	$\Delta F/F$ (HEL)
30	0.0082	0.0046
44	0.0146	0.0095
70	0.0246	0.0198
100	0.060	0.028
143	0.085	0.052

4. Lightcurves and spectra reconstruction

As confirmed by WMAP results (Bennett et al. 2003 2000), we expect to observe with Planck a large number of flat-spectrum compact objects (Toffolatti et al. 1998 2000). These sources often show strong variability. A study of the Planck capability in measuring source lightcurves at different timescales was performed. We focused upon short timescale variations (days) which can be successfully followed during a source transit through the Planck focal plane. Using available data from Cygnus X3 observations[2] and assuming a flat spectrum from 8 GHz to our channels we simulated Planck measurements of the source (Fig. 3) by considering instrumental noise only.

In the case of a bright extragalactic source, as 3C279 also considered in our simulations, this assumption is realistic and all our previous estimations are valid, while absolute mea-

[2] NRAO database available at http://www.gb.nrao.edu/fgdocs/gbi/gbint.html

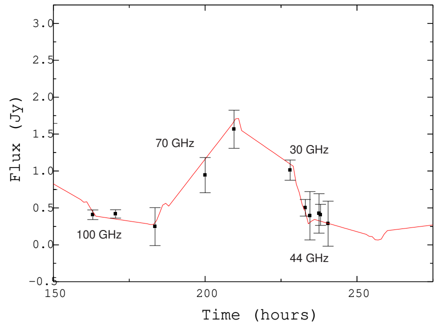

Fig. 3. Cygnus-like lightcurve recovered with the LFI 30–70 GHz channels and the HFI 100 GHz channels for a source at medium ecliptic latitudes.

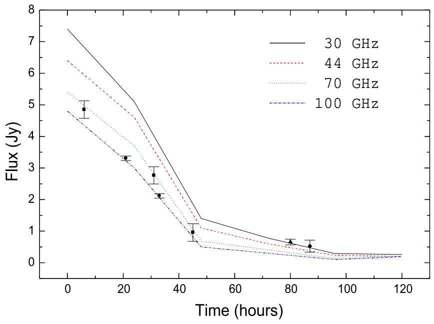

Fig. 4. Cygnus lightcurve recovered with the LFI 30–70 GHz channels and the HFI 100 GHz channels, differencing two transit data (one flaring and the other quiescent); measured points at different frequencies well fit with input data (curves).

sures of sources at low Galactic latitudes can not be easily obtained because of the relevant diffuse Galactic emission. We then tried to reconstruct the source flux behaviour, taking also into account the real spectrum (Miller-Jones et al. 2002 2000), differencing between data of the two Planck surveys. The results (see Fig. 4) are quite promising.

The Planck capability in evaluating the

Table 3. Input and fitted source spectrum parameters.

	Input	Fitted
F_0 (Jy)	1.0	1.001±0.043
α	0.0	-0.011±0.037
F_0 (Jy)	1.0	0.997±0.039
α	-0.5	-0.492±0.029
F_0 (Jy)	1.0	1.002±0.046
α	0.5	0.513±0.054

source spectrum was finally estimated assuming a stable source signal and averaging data from all channels at the same frequency. Input and recovered spectrum parameters are compared in Tab. 3. In the case of normal synchrotron, flat and inverted spectrum (α = 0.5, 0, -0.5), we simulate and fit the data according to the power law $F(\nu) = F_0(\nu/30\mathrm{GHz})^{-\alpha}$.

In the range 30–143 GHz, the spectral index will be recovered with a great accuracy for sources with flux at the Jy level. For weaker sources we find typical errors on α of 20 %. These data could represent a significant scientific result filling the current gap in the knowledge of radiosource spectrum at millimeter wavelengths.

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