Internal Report IASF-BO 440/2006

March 16, 2006

Planck-LFI
In-flight Main Beam Reconstruction Code Users's Guide Issue 1.0

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Document: PL-LFI-PST-MA-003
Revision: Issue 1.0; March 16, 2006
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Current code version: 1.0 - March 2006

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SUMMARY – This document describes the use of the in-flight main beam reconstruction code delivered to the Planck-LFI DPC and the kinds of limitations and applicabilities to simulation and data analysis activities. This code is delivered in the context of the Level 2 Planck-LFI DPC activity.
The Planck-LFI DPC of Trieste has the responsability of the software which is stored in the Planck-LFI Software Repository system under CVS.
Account to the LFI Software Repository can be obtained from the LFI DPC for the LFI consortium members.
The author is available for assistance during integration. In a future work, the integration with celestial mechanics codes and/or tabulations will be addressed.

1 Introduction

One of the most important issues in the context of PLANCK Low Frequency Instrument (LFI) experiment (Mandolesi et al. 1998) and in general in cosmic microwave background (CMB) anisotropy projetcs is the reconstruction in flight of the main beam shape. This manual describes the usage of a minimization code written in `FORTRAN` for the recovery of the main beam shape parameters. The reader can refer to the reported references for further information concerning the formalism, quality, and results of this code (Burigana et al. 2000, 2001) and for its applicability to simulated or real data (Maris & Burigana 2006).

The code exploits the time ordered data (TOD) during bright source transits on the PLANCK beams to fit the parameters describing the main beam shape in the PLANCK field of view plane. Here bright source means any source bright (i.e. with a signal well above the noise), stable (i.e. with negligible, or accurately monitored, flux variations during the transit) and point-like (i.e. with angular size much less the the beamwidth) enough to allow a sufficiently accurate beam reconstruction. The definition of the list of sources suitable for this purposes is in progress (see Burigana & Mercier 2006 for a preliminary definition of criteria of source selection).

The most promising case from this point of view is the use of bright external planets (mainly, Mars, if possible according to the launch date, Jupiter and Saturn). Of course, this case represents also the most complicate one to implement in practice because of the varying position of Solar System bodies that calls for a link with the results from accurate and up-dated celestial mechanics codes able to exploit up-dated information as well as light time-delay and aberration. Different specific considered tasks require a more or less accurate celestial mechanics treatment as well as a more or less refined description of the PLANCK varying position (see Maris & Burigana 2006). The coupling with this aspect is the object of a next document. This note is independent of the accuracy and the adopted approximations concerning the above input data.

2 What input data are needed?

The code assumes to have:

1) A preliminary approximate information on the main beam shape input parameters and their possible ranges. These data are available from optical simulations and will be available from ground testing and calibration. This is a list of parameters (see Sect. 7).

2) TOD giving lists of: the signals (possibly in antenna temperature) during the transit; the positions (x, y) of the considered source on the PLANCK telescope field of view plane frame during the transit; in the case of a planet, the distances from PLANCK of the considered planet during the transit. TOD are matrices in the current implementation, with rows corresponding to scan circles and columns to positions along each scan circle. Different convention can be easily implemented in the data acquisition.

Note that these input require, in the case of planets, to know the PLANCK position and the orientation of the PLANCK telescope field of view frame and planet positions during the transit. Any reference system is equivalent, since only vector differences have to be calculated. In the case of distant bright sources, only the orientation of the PLANCK telescope field of view frame is necessary and the matrix of distances can contain a constant value without code changes.

3) Optionally, TOD giving lists of: simulated instrumental white noise or simulated instrumental correlated (white plus $1/f$-like and/or thermal drifts, and so on) possibly previously reduced through a destriping code. This input is necessary for simulations if the signal does not include the noise and one would like to test the code in the presence of noise (clearly, it is

unuseful for real data that obviously include the noise). In this case, the noise is added to the signal. (Note that antenna temperature and surface brightness are additive, while thermodynamic temperature should be avoided being not additive). TOD are matrices in the current implementation, with rows corresponding to scan circles and columns to positions along each scan circle. Different convention can be easily implemented in the data acquisition. If the matrix is set to 0 it does not produce effect.

All the above matrices have to be ordered according to an omogeneous criterium.

Note that the code can work on both the entire set of data and binned (or coadded) data. A previous extraction of the data in order to select the appropriate limited set of data where the source signal is larger than the noise (and the signal from other cosmological and astrophysical components) is obviously necessary.

Binning and/or coadding could be in principle applied in time domain and in phase (position on the scan circle) domain. A step in the phase domain significantly smaller than the beamwidth is necessary. In order to test the beam reconstruction quality only this condition is required. On the contrary, for a realistic beam reconstruction also a small step in time binning is necessary in order to work with negligible source position variations in each data sample. For example, even a small step in phase binning but applied to data from a given spin axis position corresponding to one hour in time (fully appropriate for other applications) will introduce relevant angular errors at few arcmin level when applied to Solar System bodies.

Note that the beam reconstruction quality is significantly degraded in the presence of significant $1/f$ noise or thermal drifts not previously reduced. Note also that a proper exclusion of the limited set of data in the scan circles corresponding to bright moving sources is needed in order to avoid possible relevant errors in the recovery of the drift levels in applying destriping codes.

4) An estimate of the *rms* noise (err in the code) corresponding to the sensitivity of ensamble of signal data. This is a scalar quantity. This parameter is necessary for an appropriate $\chi^2/d.o.f.$ analysis.

5) Optionally, a parameter (div_noise in the code) for which the noise matrix and the estimate of the *rms* noise can be divided. This is the case for example in which, for simulation activity, one would like to test the sensitivity in beam reconstruction from multiple transits without repeating the simulation. This is a scalar quantity. If set to 1 it does not produce effect.

6) Optionally, a parameter (sigma_clipping in the code) determining a threshold for the signal-to-noise ratio: only data with signal above the threshold are used in the code. This is a scalar quantity. If set to 0 it does not produce effect.

3 What available software if needed?

The code uses the `MINUIT` package of the `CERN Program Library` (http://cernlib.web.ch/cernlib/).

These (free) packages have to be installed.

If data acquisition is performed with `FITS` files, the proper packages are required.

4 Current code input

1) A file with the containing the names of:

– the file for the x position of the planet on the Planck telescope field of view plane frame;

– one file for the y position of the planet on the PLANCK telescope field of view plane frame;

– one file for the distance of the planet from PLANCK;

(See also the code section "PLANET MAIN DISTANCE COMPUTATION" in `min_elli.for`)

– one file for the signal;

– one file for the noise (optional);

– the value of err;

– the value of div_noise;

– the value of sigma_clipping;

(See the code section "READING OF RELEVANT DATA FILE NAMES and PARAMETERS" in `min_elli.for`)

2) Obviously, all the files mentioned above. (See the code section "READING OF DATA FROM FILES" in `min_elli.for`)

3) An input parameter file containing initial values, ranges, and commands according to the `MINUIT` package.

5 Current code sources and compilation

The code sources are:

4) The `minuits.for` program that have to be properly compiled with the below `min_elli.for` subroutine and, obviously, with the `MINUIT` package of the `CERN Program Library`.

5) The `min_elli.for` subroutine where data acquisition and the function to minimize (see the code section "CHI SQUARE COMPUTATION") are given. This subroutine is the "core" of the code. In the current implementation a fit with a Gaussian (possibly bivariate) beam shape profile projected on the PLANCK telescope field of view plane frame with arbitrary centre, orientation, width, and axial ratio is available. The code gives also the source signal at maximum. Different main beam representations, possibly inferred on the basis of optical simulations, can be implemented in the framework of this code.

Compilation:

6) A simple text file for compilation instruction (machine dependent) is provided.

6 Current code output

The code produce an output file according to `MINUIT` format containing best fit values, errors and correlation coefficient (symmetric/parabolic errors or positive/negative errors) for the selected parameters, namely:

– 1. alpha = inclination angle of the beam major axis with respect to the x axis of the PLANCK telescope field of view plane frame;

– 2. x0 = x coordinate of the beam centre on the PLANCK telescope field of view plane frame;

– 3. y0 = y coordinate of the beam centre on the PLANCK telescope field of view plane frame;

Note that x, y and x0 and y0 are dimensionless coordinates on PLANCK telescope field of view plane frame; they approximately correspond to angular distances in rad.

– 4. sigma = beamwidth;

Note that sigma is formally a dimensionless width of the beam projected on PLANCK telescope field of view plane frame; in practice it corresponds to the beamwidth in rad since projection corrections are very small.

– 5. r = ratio between major axis and minor axis of the best fit ellipse describing the beam shape projected on PLANCK telescope field of view plane frame;

– 6. rk = source signal at maximum (in the adopted units, example antenna temperature in mK).

Note that one (or more parameters) can be fixed at the desired value, as possibly appropriate in the presence of well established prior(s), by simply using the `MINUIT` command `fix` *parameter number*.

The errors on recovered parameters can be found at the desired CL by simply using the `MINUIT` command `error def`.

Finally, note that, since the PLANCK instruments operate while the spacecraft is spinning, the reconstructed parameters give the best fit representation of the effective main beam shape including a beam smoothing along the scan circle direction related to the effective data sampling (see Burigana et al. 2001 for a further discussion). This shape, slightly different from that derived from pure optical simulation or ground measures, is in reality the most useful one for data analysis purposes. Decreasing the angular size spanned by the data sample reduces the difference between the two representations. While a time-deconvolution approach is needed for a direct comparison with the pure optical beam representation, is it probably more reliable and less time consuming a comparison of the results obtained with this code with the pure optical beam shape time-convolved along the scan circle direction.

7 Conclusion and delivery

The reader is reminded to dedicated references (Burigana et al. 2000, 2001) for descriptions about the code results and quality.

In the delivered package
(cburigana_mainbeam_recovery_2006_issue1_0.tar.gz)
the `FORTRAN` code, including
the subroutine `min_elli.for`
and the program `minuits.for`,
and some example files are given.
Namely:
link_minuit_example.txt
minuits_IO_file_delivery.dat
x_jup.sub1
y_jup.sub1
d_jup.sub1
t_1024_onlyjup_1e3_90_30ghz.sub1
white_1024_90_30ghz.sub1_jup
noise_1024_90_30ghz.sub1_jup
minuits_delivery.par
minuits_delivery.out

8 Documentation

This manual and the related works (references [1], [2], [3], [5]) are also contained in the delivered package cburigana_mainbeam_recovery_2006_issue1_0.tar.gz .

9 Future activity

The author is available for assistance during integration.

In particular, efforts are needed for the interface with simulated data from Level S and with the real data in the context of Level 2 activity.

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The extraction of the parts of TOD relevant for main beam reconstruction from bright sources is an activity related to source quick look detection. Concerning planet transits, it could be directly investigated on the basis of results from celestial mechanics codes, given the spacecraft position and pointing.

In a future work, the integration with celestial mechanics codes and/or tabulations will be addressed (see, e.g., Maris & Burigana 2006 for a preliminary investigation).

In the future, different functional forms describing the beam shape could be implemented in the same code framework. This activity will be based on optical simulation results and ground measures. The relevance of working on further approximations will be test in the context of the extensive Planck LFI simulation and data analysis activity in the possible presence of significant limitations of the adopted Gaussian bivariate approximation when compared with realistic simulated beam shapes.

Finally, this code directly provides the recovery of the main beam centre coordinates (x0,y0) on the Planck telescope field of view plane frame. When applied to the whole set of LFI receivers, it can be then used as a “key algorithm” for reconstructing/checking/updating the whole main beam LFI pointing information matrix (and then the SIAM file) in a collaborative work between HFI and LFI DPCs (see, e.g., Burigana & Mercier 2006).

References

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