TITLE:	**Tracking Solar System Objects in Planck Data**
DOC. TYPE:	**TECHNICAL NOTE**
PROJECT REF.:	**PL-LFI-OAT-TN–038** **PAGE: I of IV, 10**
ISSUE/REV.:	**1.0** **DATE: 28 October 2006**

Issued by	Michele Maris Carlo Burigana	Date: Signature:	28 October 06
Agreed by	A. ZACCHEI LFI DPC Manager	Date: Signature:	28 October 2006
Approved by	R.C. BUTLER LFI Program Manager	Date: Signature:	Xxx ____________________
Approved by	N. MANDOLESI LFI Principal Investigator	Date: Signature:	Xxx ____________________

DISTRIBUTION LIST

Recipient	Company / Institute	E-mail address	Sent
A.Zacchei	INAF-OAT	zacchei@oats.inaf.it	

CHANGE RECORD

Issue	Date	Sheet	Description of Change	Release
0	2006 Oct 11		Starting of the document	0
0	2006 Oct 12		Number assigned, Issued for LFI/DPC comments	1
1	2006 Oct 28		First Issue	0

TABLE OF CONTENTS

1 SCOPE

This document deals with tracking of Solar System Objects (SSOs) in the Planck data.

Tracking has two aspects:

1. possibility of a fast (within a week from data acquisition) identification in Time Ordered Data (TOD) with the aim of recognizing the SSO nature of possible spikes in the data (calibrated or not);
2. periodic scientific exploitation of calibrated data with the aims following:
   a) cleaning/flagging of data from SSO contaminations;
   b) beam reconstruction [RD-1];
   c) scientific studies of SSOs [AD-1, RD-1].

1.1 LIMITS OF APPLICABILITY

This document outlines a procedure to track SSO transits in the Planck beams.

The analysis is limited to at least already geometrically calibrated data.

Each time we use the words “Direction in the sky” or “Positions in the sky” we refer to J2000, angular, ecliptical coordinates.

Having to deal with Horizons program, which uses UT as time unit, it is assumed that the time scale used in data have been already calibrated in this unit.

Each time the words “Epoch” or “time” is used, it is intended it refers to UT.

The method outlined here is applicable both to LFI and HFI.

For LFI we focus on both aspects 1 and 2.

For HFI we focus only on aspect 2.

Most of the concepts behind this subject may be found in [RD-2].

2 APPLICABLE/REFERENCE DOCUMENTS

2.1 APPLICABLE DOCUMENTS

[AD–1] *Asteroid detection at millimetric wavelengths with the PLANCK survey*
G. Cremonese, F. Marzari, C. Burigana, M. Maris
New Astronomy, 2002, 7, 483

[AD–2] *Planck LFI – On Moving Objects Solar System Calculations*
M. Maris, C. Burigana
PL-LFI-OAT-TN-034, Ver. 1.0, 28 Mar 2006

2.2 REFERENCE DOCUMENTS

[RD–1] *In Flight Main Beam Reconstruction for Planck LFI*
C. Burigana, et al.,
2001, Experimental Astronomy, 12, 87

[RD–2] *Horizons Manual*
Release 2005 January 04
ftp://ssd.jpl.nasa.gov/pub/ssd/Horizons_doc.pdf

2.3 ACRONYMS LIST

DPC	Data Processing Center
FD	Flight Dynamics
FM	Flight Model
FS	Flight Simulator
L2	Second Lagrangian Point of the Sun-Earth System
LS	Level S
OBT	On Board Time
SS	Solar System
SSO(s)	Solar System Object(s)
TBC	To Be Confirmed
TBD	To Be Defined
TOD	Time Ordered Data
TOD	Time Ordered Data
TOI	Time Ordered Information
MBA	Main Belt Asteroids
FOV	Field of View

DBMS	Data Base Management System
JPL	Jet Propulsion Laboratory
SN	Signal/Noise ratio
KBO	Kuipert Belt Objects
CSV	Comma Separated Values

3 CLASSIFICATION AND NUMBER OF OBJECTS

In this context, it is useful to classify SSOs according to the following scheme:

I. SSO fully negligible (typically S/N < 0.1);
II. SSO allowing a S/N < 1 for averaged sampling but non-negligible (typically S/N > 0.1);
III. SSO allowing a S/N > 1 at least in one frequency channel for averaged sampling.

Group III consists of objects suitable for scientific exploitation of data; group II. consists of objects which may represent a source of contamination of data.

We have to track:

1. External planets (5 objects)
2. Main Belt asteroids (MBA) (~1000)
3. Periodical comets (~1000)
4. Bright non periodical comets (not determined, about few per year)
5. The largest or nearest KBOs (Pluto, ... a few objects)

To decide which SSO enter category II. or III., for the class 2 and 5 we can refer to [AD-1] where a threshold criterium in terms of R/D is given; here R is the object radius and D its distance from the observer, a typical threshold being $R/D > 10^{-7}$ for S/N > 1.

For comets the situation is more complex and still TBD, since the critical parameter is the R/D where here R is the radius of coma which cannot be predicted easily in advance. In general it is clear that periodical comets shall be monitored and that only at the epoch of observation it will be possible to judge whether they are relevant or not. For non periodical comets similar considerations hold, but taking also in account that even the geometrical aspect has to be defined at the observation epoch.

4 IDENTIFICATION

The term *identification* means here that we are able to decide whether a SSO is relevant or not regarding to categories I, II or III for a given sample.

The identification of a SSO is based on its position in the sky at the epoch of observation as predicted by a suitable program or data-base of ephemerides.

The SSO position has to be compared with the pointing directions of the various Planck beams. Relevant metrics are (see Fig.4.1) [1]:

a) SSO epoch of observation;
b) SSO angular distance from the beam centre ρ;
c) SSO position angle (relevant for not symmetric beams) P_B;
d) SSO range of likely fluxes compared to the instrumental noise for the given sample.

We need to:

1. determine a list of potential interesting SSO for each observation epoch
2. compute their precise location in the sky with respect to Planck
3. compute the metrics listed above for the selected objects and the selected samples
4. decide if a given SSO belongs either to category I, II or III with respect to each selected sample.

Step 1. is motivated by the need to avoid to perform the time-consuming subsequent steps for a useless large number of objects, which by geometry are not relevant. It can be achieved by working with low-precision/low-resolution celestial mechanics modelling. Subsequent steps requires accurate computations.

The accuracy of the above calculations are connected to the accuracy by which the pointing and the position of Planck within the Solar System are known. It is likely that during operations the information about the pointing law as the orbit will be time by time updated, so that steps from 2 to 4 will have to be repeated for the already analysed data.

[1]Note that metrics b) and c) are chosen for simplicity of definition and calculation. Alternatively to b) and c), another couple of suitable coordinates could provided, the best choice being related to the data model and the efficiency of the geometrical computation.

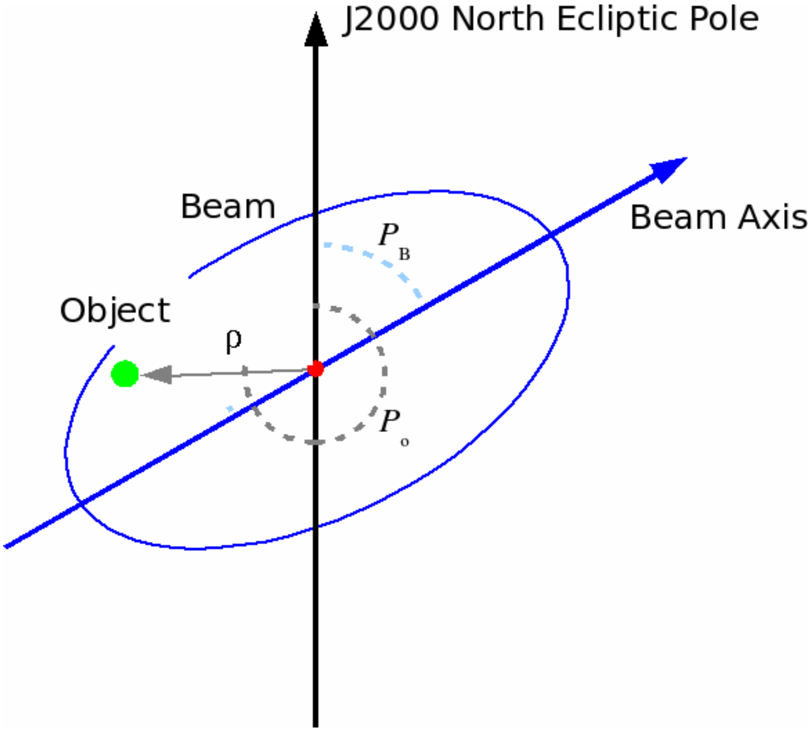

Fig.4.1 Geometry of a SSO position with respect to a main beam.
Here P_B is the position angle of the main axis of the beam, P_O is the position angle of the SSO, and ρ is the angular distance of the source from the beam centre direction. Reference frame is ecliptical J2000. Angles are counted from the meridian passing through the beam centre direction.

5 HORIZONS AND RELATED TOOLS

The JPL Horizons system (http://ssd.jpl.nasa.gov/?horizons) has been already discussed in [AD-2] and is documented in [RD-2].

Horizons is perhaps the most accurate and flexible tool in the network. It allows calculation for planets and about 170000 minor bodies (asteroids and comets) and even the L2 libration point. It allows calculations for geocentric observers, barycentre observers, and some pre-selected space missions. It can be accessed by the network with three interfaces: web based, telnet (interactive) and email, but users are not allowed to add their own orbit files for specific missions.

Recently (2006 august 31), an orbit for Planck covering the interval from 3 August 2007 to 26 April 2010 has been added, so that Horizons is now implemented to compute the apparent position of any SSO as seen from Planck in this time period [2] and assuming that the orbit given in input is the true orbit of the satellite.

We expect in the future that as soon as new, updated orbits, will be provided by the Planck collaboration, these will be given to the Horizons team to update the code too.

5.1 USAGE OF HORIZON

5.1.1 PLANETS AND BRIGHT OBJECTS

For Planets, and the brightest SSOs of categories 2, 3 and 5 the most practical possibility is to use Horizons once the Planck orbit is defined to obtain accurate tabulations of the apparent positions of these objects as seen by Planck all over the mission. We expect to consider in this case no more than about 50 – 100 SSOs. The time resolution of these tabulation will be approximately 10 minutes - 1 hour with the best approximation perhaps needed for Mars and / or some comets.

5.1.2 NON PERIODIC COMETS

In case of non periodic comets the tabulation, with a resolution compared to that in Sect.5.1.1, but likely for shorter time spans, will have to be provided case by case during the mission.

5.1.3 MINOR OBJECTS

In case of less bright objects it is important to apply Step 1 of Sect.4.

Step 1. is based on a very rough tabulation as described below:

[2]Before 31st August 2006, in particular at the time in which [AD-2] has been prepared, this was not possible.

1. it is stored and used locally;
2. it is for all of the about 2000 objects in the categories 2, 3 and 5;
3. typically it has time resolution of few days up to a week;
4. it is (re)generated by using Horizons as soon as a significant changes in the orbit of Planck are introduced.

Given the Planck scanning strategy and the size (about 8 degrees) of its field of view (FOV) the following metrics are computed:

1. epoch of observation and time interval of observation (daily or weekly);
2. directions of spin axis for the epoch of observation;
3. angular distance between the spin axis and the objects at the given epoch (if needed, interpolations of positions of objects at the epoch of observation can be performed);
5. determination of the list of potentially interesting SSOs for the given observation epoch is obtained looking for those objects whose angular distance from the spin axis is within 85º ± 6º [3].

We expect to select about some tens of objects per day.

From this list of potentially interesting selected objects a set of queries to Horizons is produced for the considered time span.

Horizons is then again queried at high time resolution, typically from 10 minutes to 1 hour, for each of these objects. The resulting high accuracy tabulations are processed as steps 2 to 4 of Sect.4 as in the case of the brightest objects.

Finally, we note that in the case of LFI, only relatively bright SSOs are expected to produce relevant signals [see AD-2]. For LFI it could be then more advantageous to treat minor objects as discussed in Sect.5.1.1, possibly by slightly extending the considered set of objects. On the other hand, the real applicability of this possibility need to be properly evaluated by dedicated simulations that necessarily require the use of the strategy discussed in this subsection.

5.2 METHODS TO ACCESS TO HORIZONS

Given the high number of accesses to Horizons required by this plan, an automated method to query Horizons, download and interpret results is required.

We suggests to use automatic email processing to query Horizons and download data.

Horizons can be accessed via WEB interface, telnet or email [RD-2].

[3] In fact, the angle between the spin axis and the telescope axis is 85º. The choice of 6º corresponds to half FOV plus a 50% allowance.

The simplest way is the WEB interface, but writing a WEB based application is not easy. In addition, not all the possible options of the system can be accessed in this way. The WEB interface has been redesigned time-by-time in the past. The use of the WEB interface would be then complex and risky.

The telnet access is designed for interactive use. Only one job at a time may be submitted. Results can not be downloaded but only sent by email to the user.

Consequently, the email access is the best choice providing that:

1. it is based on a simple query form to be sent by email;
2. it allows the same functionalities of the telnet interface;
3. it allows the splitting of large sets of queries in more handleable subqueries;
4. the email content is standardized; it is written CSV format and it is of simple interpretation;
5. a typical email of results calculated for 3 years of computed positions, sampled at 1 hour resolution, for a single SSO would be about 2 Mbyte large.

The preferred format of output data is CSV.

6 SYSTEM REQUIREMENTS

6.1 RESOURCES

1. Availability of updated Planck orbit information at Horizons site.
2. Availability of Horizons email interface (this includes the possibility to send and receive in an automated manner emails by using, as an example, the sendmail service).
3. Availability of a local ephemerides tabulations (approximately 200~MBytes for each version of the tabulation, the version will change as soon as the orbit will be significantly changed).
4. Availability of updated Planck scanning strategy information.
5. Availability of a "repository" where to store tables (at this level, "repository" indicates something simple as an organized set of files up to a dedicated DBMS).

6.2 FUNCTIONS

1. The system shall be able to query Horizons to generate all the required tables.
2. The system shall be robust against failures, delays in Horizons answers (if Horizon fails the system shall not stop abruptly).
3. The system shall be able to ingest Horizons tables in the repository.
4. The system shall be able to search in the repository looking for a given object at a given epoch of observation.
5. The system shall be able to interpolate object positions at given epochs.
6. The system shall be able to accept list of samples, having for each sample the Epoch of acquisition, the beam direction in the sky, the beam position angle, the noise level.
7. The system shall be able to accept list of Spin axis directions, having for each Spin axis direction the interval of Epochs in which it has been held fixed in space.
8. The system shall be able to calculate, for a given Spin axis and a given epoch, the angular distance between the Spin axis and each selected object in the repository.
9. The system shall be able to use the angular distance between the Spin axis and each selected object in the repository to identify the potentially interesting SSOs.
10. The system shall be able to generate refined queries to Horizons for the potentially interesting objects and to use the output to generate refined tables.
11. The system shall be able to use the refined tables.
12. The system shall be able to calculate, for a given sample (characterized by acquisition time and pointing direction), the angular distance from the beam centre, the position angle and an approximated flux estimate for each selected object in the repository.
13. The system shall be able to classify the objects according to the categories in Sect.3.
14. The system shall be able to issue a list of flags for each analysed sample according to the Table 6.1.

15. The system shall be able to count the number of objects affecting each given sample and to provide it in output.
16. The system shall be able to generate, for each sample and on request, the list of objects affecting each sample together with the already mentioned metrics.

Table 6.1 Flags for Samples

Value	***Meaning***
0	No SSO inside
1	SSO of Category I
2	SSO of Category II
3	SSO of Category III