SPICE Lander Ancillary Data Status

SPICE

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1 Introduction

1.1 Purpose and Scope

This document describes the current status of the Rosetta Lander SPICE kernels under the responsibility of the ESA SPICE Service (ESS). To a certain extent it also covers most of the data included in the Lander Ancillary Data Dataset archived in the PSA.

1.2 References:

1. ``PHILAE: DESCRIPTION OF DATA DELIVERED TO PSA & PDS'', ROS-TNO-LTAN-8880-CN, R. Garmier, Issue 0, Revision 1, 15th September 2015.

2. ``Philae Localization and Science Support by Robotic Vision Techniques'', E. Remetean et al., Acta Astronautica, Volume 125, p. 161-173, October 2016.

3. ``Attitude reconstruction of ROSETTA′s Lander PHILAE using two-point magnetic field observations by ROMAP and RPC-MAG'', P. Heinisch, et al., Acta Astronautica, Volume 125, August–September 2016, Pages 174-182, October 2016.

4."COORDINATE SYSTEMS FOR ROSETTA", Richner M., Gebauer G., Leissle T., Astrium, RO-DSS-TN-1081, Issue 6D, 17th September 2003.

2 Overview:

This data set contains the complete ancillary information for the Rosetta Lander, namely; trajectory, attitude and position. The source data were generated by the CNES/SONC-FD team, the RPC-ROMAP team at LAM and the CONSERT team. The corresponding SPICE kernels have been generated by the RSGS and the ESA SPICE Service (ESS).

The data concern three different phases of the Philae mission

1. SDL (Separation Descent Landing), the descent ranging from the release of Philae to the first touchdown
2. RBD (Rebounds), the rebound ranging from first touchdown to final landing.
3. FSS (First Science Sequence), the rest on the final landing site.

Timetable of the main events occurring during the Philae Mission:

Mission Phase	Event	Time (UTC)	Time (TDB)
SDL	Release of Philae	2014-11-12T08:35:00	2014-11-12T08:36:07
SDL	Unfolding of the landing gear	2014-11-12T09:05:00	2014-11-12T09:06:07
SDL-RBD	First Touchdown (TD1)	2014-11-12T15:34:03	2014-11-12T15:35:10
RBD	Second Touchdown (TD2)	2014-11-12T16:20:00	2014-11-12T16:21:07
RBD	Third Touchdown (TD3)	2014-11-12T17:25:26	2014-11-12T17:26:33
RDB-FSS	Final landing (FL)	2014-11-12T17:31:17	2014-11-12T17:32:23
FSS	Start of First Science sequence	2014-11-12T17:31:17	2014-11-12T17:32:23
FSS	End of First Science sequence	2014-11-14T22:18:01	2014-11-14T22:19:08

Remark: Philae ended its First Science Sequence and fall into hibernation. It seems it wake-up the 26 April 2015. First communication with Rosetta occurred the 13 of June 2015 and the last one the 9 of July. No scientific measurement has been collected after the end of FSS and therefore is not contemplated in this dataset.

The comet shape model that has been used to produce the original ancillary data is cg-spc-shap5-v1.0-cheops (CSHP_DV_085_01_______00145.ROS)

The available products are described in the next section. Please note that those highlighted with bold and grey background are the kernels which are recommended to be used and the ones which are included in the latest Rosetta operational and archived meta-kernel.

2.1 Trajectory

Name	Source	Kernel Generator	Start Coverage	Finish Coverage
LORB_SUN_J2000_SDL_V1_0.BSP	SONC	RSGS	2014 NOV 12 08:36:07.182	2014 NOV 12 15:35:21.361
LORB_SUN_J2000_RBD_1_V1_0.BSP	SONC	RSGS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:31:41.440
LORB_SUN_J2000_RBD_2_V1_0.BSP	SONC	RSGS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:32:56.333

Name	Sonc	Kernel Generator	Start Coverage	Finish Coverage
LORB_SUN_J2000_RBD_3_V1_0.BSP	SONC	RSGS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:28:00.457
LORB_SUN_J2000_RBD_4_V1_0.BSP	SONC	RSGS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:25:16.606
LORB_SUN_J2000_RBD_5_V1_0.BSP	SONC	RSGS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:32:46.873
LORB_SUN_J2000_RBD_6_V1_0.BSP	SONC	RSGS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:30:30.642
SPICE_PHILAE_CFF_SONC_V1_0.BSP	SONC	RSGS	2014 JAN 01 00:00:00.000	2016 DEC 31 23:59:59.000
SPICE_PHILAE_CFF_SR_V1_0.BSP	SONC	RSGS	2014 JAN 01 00:00:00.000	2016 DEC 31 23:59:59.000
SPICE_PHILAE_CFF_CN_V1_0.BSP	SONC	RSGS	2014 JAN 01 00:00:00.000	2016 DEC 31 23:59:59.000
LORB_SUN_J2000_SDL_V1_1.BSP	SONC	ESS	2014 NOV 12 08:36:07.182	2014 NOV 12 15:35:21.361
LORB_SUN_J2000_RBD_1_V1_1.BSP	SONC	ESS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:31:41.440
LORB_SUN_J2000_RBD_2_V1_1.BSP	SONC	ESS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:32:56.333
LORB_SUN_J2000_RBD_3_V1_1.BSP	SONC	ESS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:28:00.457
LORB_SUN_J2000_RBD_4_V1_1.BSP	SONC	ESS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:25:16.606
LORB_SUN_J2000_RBD_5_V1_1.BSP	SONC	ESS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:32:46.873
LORB_SUN_J2000_RBD_6_V1_1.BSP	SONC	ESS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:30:30.642
SPICE_PHILAE_CFF_SONC_V1_1.BSP	SONC	ESS	2014 NOV 12 17:25:16.606	2017 JAN 01 00:00:00.000
SPICE_PHILAE_CFF_SR_V1_1.BSP	SONC	ESS	2014 NOV 12 17:25:16.606	2017 JAN 01 00:00:00.000
SPICE_PHILAE_CFF_CN_V1_1.BSP	SONC	ESS	2014 NOV 12 17:25:16.606	2017 JAN 01 00:00:00.000
SPICE_PHILAE_CFF_SONC_V2_0.BSP	SONC	ESS	2014 NOV 12 17:25:16.606	2017 JAN 01 00:00:00.000
LORB_SUN_J2000_RBD_1_V1_2.BSP	SONC	ESS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:31:41.440
LORB_SUN_J2000_RBD_2_V1_2.BSP	SONC	ESS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:32:56.333
LORB_SUN_J2000_RBD_3_V1_2.BSP	SONC	ESS	2014 NOV 12	2014 NOV 12

Name	Source	Kernel Generator	Start Coverage	Finish Coverage
			15:35:16.306	17:28:00.457
LORB_SUN_J2000_RBD_4_V1_2.BSP	SONC	ESS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:25:16.606
LORB_SUN_J2000_RBD_5_V1_2.BSP	SONC	ESS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:32:46.873
LORB_SUN_J2000_RBD_6_V1_2.BSP	SONC	ESS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:30:30.642

2.2 Orientation

Name	Source	Kernel Generator	Start Coverage	Finish Coverage
LATT_J2000_FSS_V1_0.BC	SONC	RSGS	2014-NOV-12 17:33:25.248	2015-JAN-01 00:00:26.650
LATT_EME2LDR_SDL_V1_0.BC	SONC	ESS	2014-NOV-12 08:37:08.236	2014-NOV-12 15:36:12.226
LATT_ROS2LDR_SDL_ROMAP_V1_0.BC	ROMAP	ESS	2014-NOV-12 10:36:41.560	2014-NOV-12 15:32:40.784
LATT_CFF2LDR_FSS_V1_0.BC	SONC	ESS	2014-NOV-12 17:32:24.182	2016-DEC-31 23:59:59.999
LATT_J2000_FSS_V1_1.BC	SONC	ESS	2014-NOV-12 17:32:24.183	2014-DEC-31 23:59:24.183
LATT_CFF2LDR_FSS_V2_0.BC	SONC	ESS	2014-NOV-12 17:32:24.182	2017-JAN-01 00:01:08.183

2.3 Spacecraft Clock

Name	Source	Kernel Generator
LANDER_150414_STEP.TSC	SONC	RSGS
LANDER_170904_STEP.TSC	SONC	ESS

2.4 Summary of recommended kernels

Name	Source	Kernel Generator	Start Coverage	Finish Coverage
LORB_SUN_J2000_SDL_V1_1.BSP	SONC	ESS	2014 NOV 12 08:36:07.182	2014 NOV 12 15:35:21.361

Name	Source	Kernel Generator	Start Coverage	Finish Coverage
LORB_SUN_J2000_RBD_*_V1_2.BSP	SONC	ESS	2014 NOV 12 15:35:16.306	2014 NOV 12 17:31:41.440
SPICE_PHILAE_CFF_SONC_V2_0.BSP	SONC	ESS	2014 NOV 12 17:25:16.606	2017 JAN 01 00:00:00.000
LATT_EME2LDR_SDL_V1_0.BC	SONC	ESS	2014-NOV-12 08:37:08.236	2014-NOV-12 15:36:12.226
LATT_ROS2LDR_SDL_ROMAP_V1_0.BC	ROMAP	ESS	2014-NOV-12 10:36:41.560	2014-NOV-12 15:32:40.784
LATT_CFF2LDR_FSS_V2_0.BC	SONC	ESS	2014-NOV-12 17:32:24.182	2017-JAN-01 00:01:08.183
LANDER_170904_STEP.TSC	SONC	ESS	-	-

Please note that the earlier versions of some kernels contained interpolation issues (LORB_SUN_J2000_RBD_*_V1_0.BSP) and/or where poorly commented and therefore they were reprocessed by the ESS.

3 Detailed kernel description

3.1 SDL

3.1.1 Trajectory

The input data to propagate the trajectory that has been used to is the following:

Comet models	Reference of the model	comment
Shape models	cg-spc-shap5-v1.0-cheops	Provided by OSIRIS team
Comet ephemerides	CORB_DV_106_01_______00173.ROS	Provided by RMOC team
Comet rotation	CATT_DV_106_01_______00173.ROS	Provided by RMOC team
Gravity model	GRA_GRGS_OSIRIS_V5_CU_grav.ROS	The gravity is derived from the shape model considering that nucleus has a constant density
Release bulletin	LORB_DV_106_01_______00173.ROS	Extracted from RMOC

The landing point obtained by propagation is 11 m away from the estimated touchdown site and occurred 5.1s after the observed date. The accuracy of the landing trajectory is considered as good.

The error on the propagated trajectory mainly comes from:

- The estimation of the release point of Philae (the accuracy is around 10 m)
- The gravity model and shape model

3.1.2 Orientation

SONC-FD delivered a first attitude dataset with the following description:

``Rosetta is equipped with a scientific magnetometer named RPC_MAG. Philae is also equipped with a scientific magnetometer named ROMAP. During some part of the descent ROMAP team use its magnetometer of a compass (with respect to RPC mag measurement) to determine the Philae attitude. The details of the method is described in [3].

To derive its attitude, ROMAP method requires assuming a constant period of rotation and Z lander direction for a 20 minutes time span.

The quality estimation of attitude data is tricky. We nevertheless have some idea of the attitude of Philae at release and at landing:

- The release attitude was commended to ensure that the Z lander frame is collinear with the normal to the targeted landing site.
- The landing attitude was derived by CNES using ROLIS images [2]. Unfortunately ROMAP was not deployed at release and the attitude was not estimated."

Later on, in June 2017, ROMAP provided to RSGS a new SDL attitude dataset based on combined ROMAP and CONSERT reconstructions. The description provided is as follows:

"The quaternions describe the transformation from the lander frame to the Rosetta s/c frame. They should be accurate to within approximately 10 degrees.

The first part of the descent is missing, because we had to wait for LG and ROMAP boom deployment (and a relatively steady state after deployment) and CONSERT observations are only available from around 10:30 onwards. Reconstruction of this initial part would require considerable work and would most certainly not give sufficiently accurate results.

Some data in-between is also still missing, due to interference in the ROMAP signal. Unfortunately we were still not able do determine the exact cause. The best approach might be to interpolate the missing segments (which should be reasonably accurate, as we can assume a free spinning body)."

3.2 RBD

3.2.1 Trajectory

The available data to rebuild the rebound trajectories are:

- The touchdowns and final landing dates
- An estimation of the position of the first touchdown and final landing position
- An estimations of Philae position during the fly between touchdown 1 and 2 derived from an OSIRIS image

SONC computed 6 trajectories all possible according to the optimization problem. Each trajectory is expressed in EME 2000 frame and CFF frame (i.e. two files delivered per trajectory). All these trajectories are rather different but it is not possible to say which one is the closest to the real trajectory. There are not obtained with measured data and should be considered as hypothetical trajectories.

3.2.2 Orientation

No attitude has been provided for the RBD phase and therefore it is not available.

3.3 FSS

3.3.1 Position

The final landing site is the point where Philae came at rest on the comet.

It was identified from the OSIRIS narrow-angle camera images taken on 2 September 2016 from a distance of 2.7 km. The image scale is about
5 cm/pixel. Philae’s 1 m-wide body and two of its three legs can be seen extended from the body. The images also provide proof of Philae’s orientation.

According to D. Popescu the final location provided by the Laboratoire d'Astrophysique de Marseille (LAM) team.

- Longitude = 358.53 deg
- Latitude = -8.10 deg

It is associated to the LAM DTM delivered in October 2016 in the OSIRIS Keops comet fixed frame.

Before the final determination of the landing site, SONC delivered three possible landing sites:

- The OSIRIS landing site based on image analysis. This landing site is consider as the best candidates.
- The SONC FD landing site. It is a few tens meter away from OSIRIS landing site but slightly outside the CONSERT possible area.

- The CONSERT landing site. It is located at the center of the CONSERT most probable zone. It is more south than the two previous landing site.

The location of the landing sites (CFF coordinates) in th cg-spc-shap5-v1.0-cheops are the following:

Source	X (km)	Y (km)	Z (km)	Lon (deg)	Lat (deg)	Radius (km)
OSIRIS	2.4440	-0.7010	-0.3546	358.35	-8.25	2.4706
SONC-FD	2.443	-0.0853	-0.3524	358.2	-8.10	2.4711
CONSERT	2.4164	-0.1012	-0.3938	357.6	-9.25	2.4503

Source	X (km)	Y (km)	Z (km)	Lon (deg)	Lat (deg)	Radius (km)
SONC-FD Final	2.4473	-0.0627	-0.3486	358.5324	-8.1042	2.472798

3.3.2 Orientation:

The attitude delivered by SONC-FD was derived by ROMAP magnetometer and later it was evaluated by SONC-FD by using the current output produced by the Philae solar arrays. ROMAP attitude is supposed to present a better accuracy than SONC-FD attitude. SONC attitude was used only to cross check ROMAP attitude. The final position of Philae is not necessary to generate this data.

At the end of the First Science Sequence (FSS) the head of Philae was rotated to improve the solar illumination of Wall 1. It means that the LDR framed was rotated as it attached to the head. As a consequence, SONC delivered an attitude file containing attitude before and after rotation of the head. The description of the rotation may be found in [2].

4 Spacecraft Clock Generation:

At first instance an experimental version of the Lander SCLK was generated to cover the need of validating some datasets that requred urgent validation and it was based on the information provided by Daniel Popescu from SONC-FD. According to Daniel, the Lander On Board Time (LOBT) had a resolution of 1/32s and it suffered 2 resets since 01/01/2003:

- 2007-04-03T10:42:07.000
- 2011-07-04T21:24:14.000

This experimental version (LANDER_150414_STEP.TSC) does not include the resets nor the appropiate resolution and it also contains a wrong reference to the ID of the Lander: it should not be used.

For the generation of the current LANDER SCLK, the following assumptions were done:

- LOBT is synchronized with OOBT
- Lander SCLK correlation is needed only for ~3 days after landing
- Lander SCLK fractional part of is a counter of 1/32 of a second (corresponds to the first 5 bits of the full two-byte, 0..65536 fractional part of orbiter SCLK)

5 Lander Extended Coverage

In order to have an extended coverage for the Lander during the whole duration of the Rosetta Mission, ESS has generated SPK and CK kernels to have extended trajectory and orientation for the Lander. and regardless of the Lander Trajectory files provided by Flight Dynamics:

Name	Source	Kernel Generator	Start Coverage	Finish Coverage
LORB_DV_145_01___T19_00216.BSP	FDy	ESS	2014 JAN 01 00:00:00.000	2015 OCT 31 01:41:08.182
LORB_DV_223_01___T19_00302.BSP	FDy	ESS	2015 FEB 25 16:15:13.182	2016 JUL 17 01:41:08.183
LORB_DV_236_01___T19_00318.BSP	FDy	ESS	2015 DEC 30 16:15:13.182	2016 AUG 18 21:01:08.18

The generated kernels, in order to cover the full Lander mission are the following:

Name	Source	Kernel Generator	Start Coverage	Finish Coverage
LORB_ROS_SC_PRESEP_V1_0.BSP	ESS	ESS	2004 MAR 02 09:26:21.583	2014 NOV 12 08:37:00.000
LATT_ROS2LDR_PRESEP_V1_0.BC	ESS	ESS	2004 MAR 02 09:32:48.581	2014 NOV 12 08:36:00.000

LATT_ROS2LDR_PRESEP_V1_0.BC provides orientation of the Lander before separation. The Lander was attached to the Rosetta Orbiter -X Panel and it had a tilt of 2.69 degrees towards the S/C -X axis.

LORB_ROS_SC_PRESEP_V1_0.BSP provides position before Lander separation. The coordinates of the ROS_LANDER frame w.r.t. to the ROS_SPACECRAFT frame center; ROSETTA are provided by [4]. The position of ROS_LANDER with respect to ROSETTA is provided by the following vector (units are km):

PHILAE_XYZ = (-0.000869, 0, 0.001326)

The following diagram shows the position of the ROS_LANDER during the pre Lander Mission phase:

```
                                     ^
                                     | toward comet
                                     |
                                            ^ +Zlnd
                             Science Deck   |
               +Zmgax         ._____________|
                     <-------o|             |
                     <-------o|             |
               +Zmgas        ||  +Zsc       |----. Lander
                             ||      ^      |  | |
                      +Xmgax ||      |      x--|-|-----> -------
                            .V|      |      |  | |   +Xlnd  |
                      +Xmgas V|      |      |----'          |
  PHILAE_XYZ[3]
                        .'    |      |+Ysc  |               |
                       o==== <-------o _____. -----------------
                      .//  +Xsc      |      |
                      |`.            |      |
                      |  \           |      |
                      |   .          |------|
                    o'|   |
```

```
                     \|    '             PHILAE_XYZ[1]
                      |   /
                      |.'
                      ' HGA                +Y solar array is not shown
                                            +Ysc, +Ymgas, and +Ymgax
                                             are out of the page.
                                            +Ylnd is into the page.
```

6 Lander data known issues

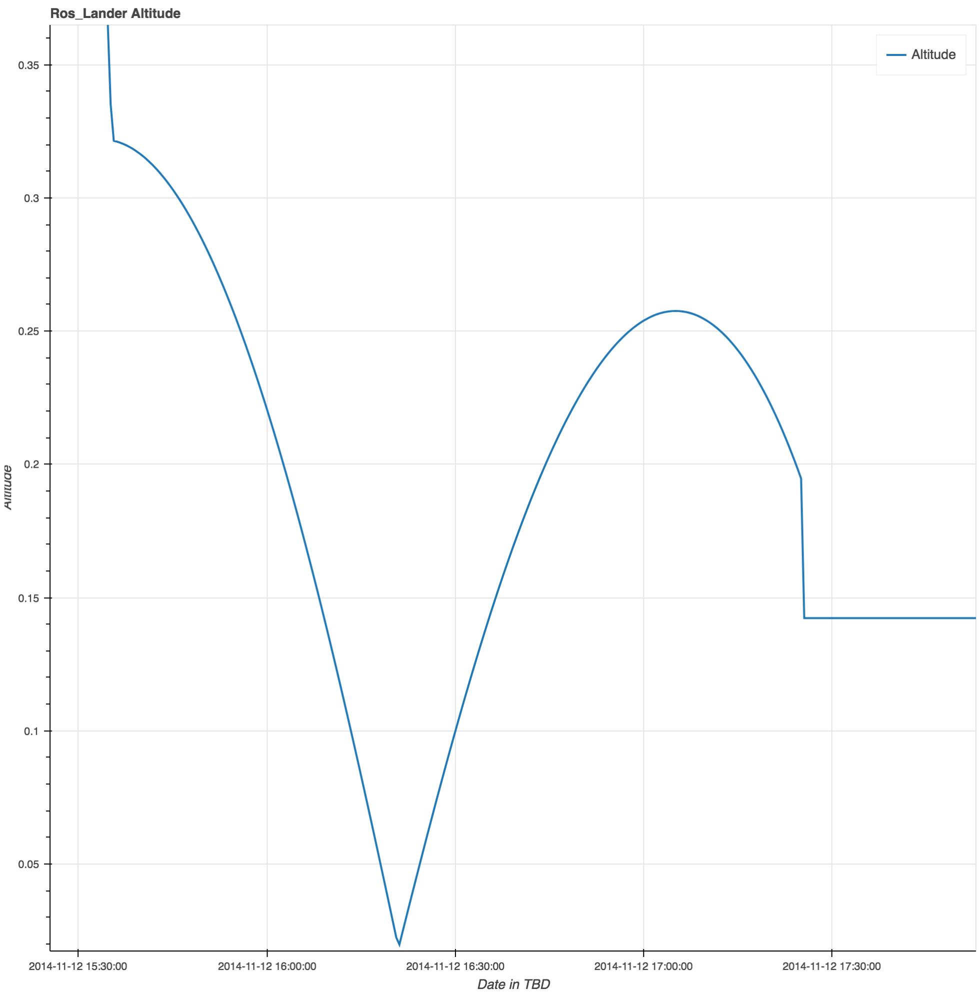
The data from which the kernels described before has been generated is complete and has some known issues which are listed in the following:

6.1 Trajectory

The Lander trajectory does not match in the boundaries of the kernels for each phase (SDL, RBD and FSS) as follows:

1. **End time of SDL is after of Start Time of all RBD candidates.**
2. **End position of SDL does not match any Start Position of any of the RBD candidates.**
3. **Each individual RBD candidate has different End Times and End positions.**
4. **End position of each RBD candidate does not match with the final landing location by SONC.**
5. **The Third Touchdown (TD3) is not modeled and is merged with the final landing.**

This is partially depicted in the following graph that shows the altitude of the Lander w.r.t 67P/C-G using the recommended kernels:



6.2 Orientation

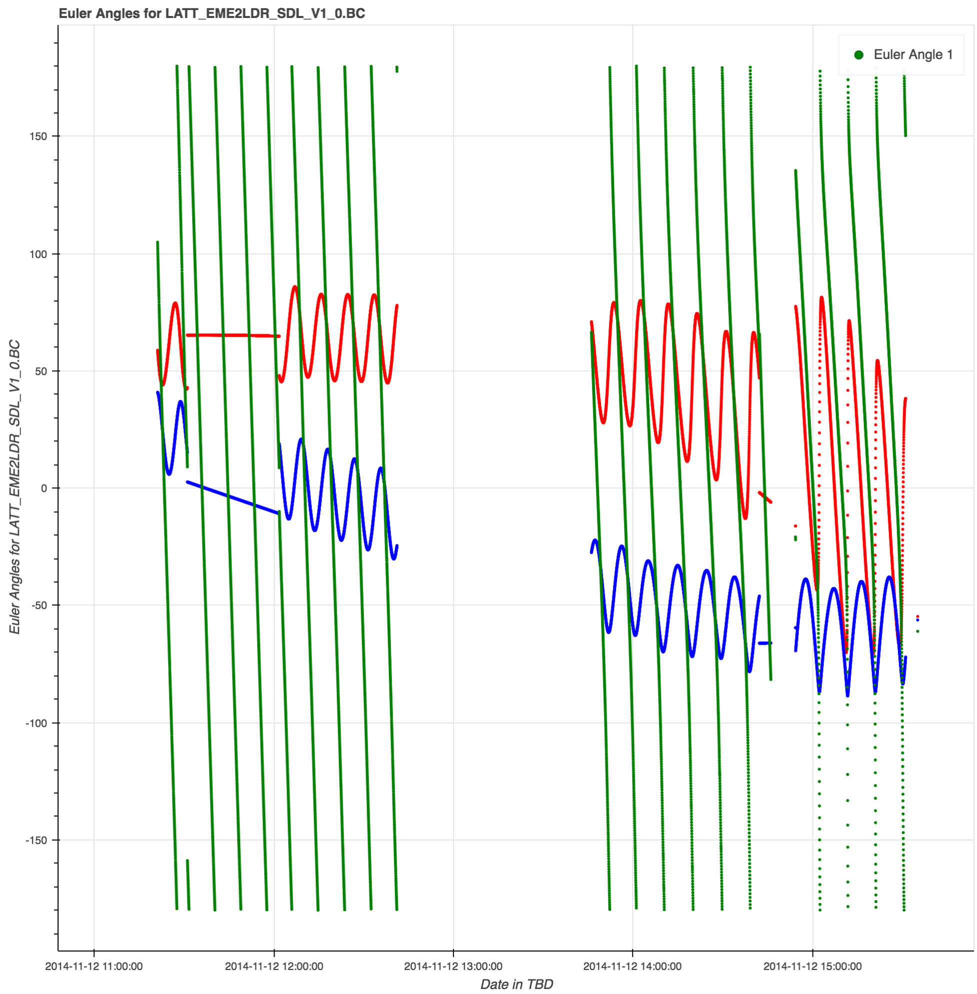
The Lander orientation is incomplete and presents the following issues:

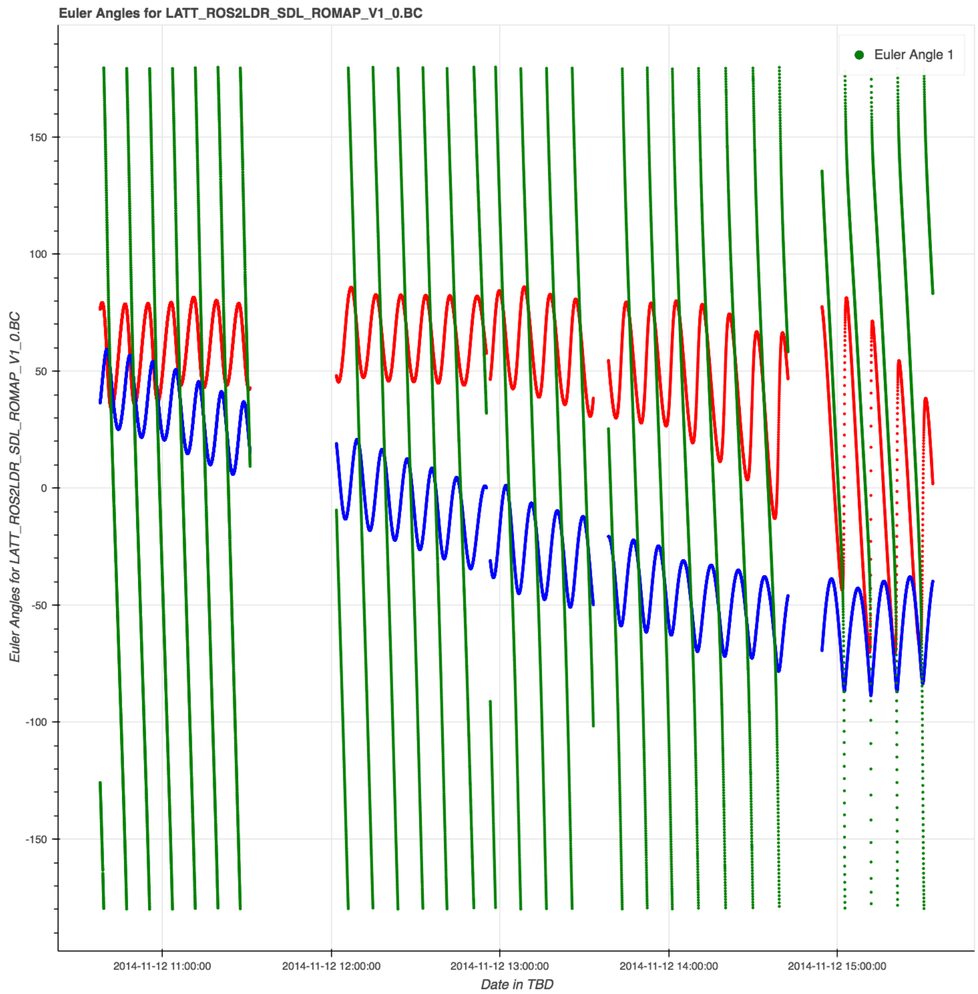
1. **There is no Attitude for the RBD phase.**
2. **The Attitude during SDL is provided by two separated kernels, although the most "accurate" one is supposed to be the ROMAP one, neither of them have full coverage and have gaps. Both of them are loaded in order to fill each other's gaps.**
3. **The Attitude during SDL does not start after separation.**

The following paragraph summarises the interpolation intervals for each of the SDL kernels:

```
Summary for: LATT_ROS2LDR_SDL_ROMAP_V1_0.BC

Segment No.: 1

Objects Interval Begin ET Interval End ET AV
-------- ------------------------ ------------------------ ---
-226800 2014-NOV-12 10:37:48.742 2014-NOV-12 11:31:07.493 Y
-226800 2014-NOV-12 12:01:48.368 2014-NOV-12 12:55:07.807 Y
-226800 2014-NOV-12 12:56:28.870 2014-NOV-12 13:33:07.777 Y
-226800 2014-NOV-12 13:38:28.964 2014-NOV-12 14:42:17.965 Y
-226800 2014-NOV-12 14:54:23.997 2014-NOV-12 15:33:47.966 Y


Summary for: LATT_EME2LDR_SDL_V1_0.BC

Segment No.: 1

Objects Interval Begin ET Interval End ET AV
-------- ------------------------ ------------------------ ---
-226800 2014-NOV-12 08:36:07.181 2014-NOV-12 08:36:07.192 Y
-226800 2014-NOV-12 11:21:09.182 2014-NOV-12 12:41:10.182 Y
-226800 2014-NOV-12 13:46:09.182 2014-NOV-12 14:46:08.182 Y
-226800 2014-NOV-12 14:54:21.182 2014-NOV-12 15:20:56.182 Y

Segment No.: 2

Objects Interval Begin ET Interval End ET AV
-------- ------------------------ ------------------------ ---
-226800 2014-NOV-12 15:20:48.182 2014-NOV-12 15:31:11.182 Y
-226800 2014-NOV-12 15:35:11.152 2014-NOV-12 15:35:11.162 Y
```

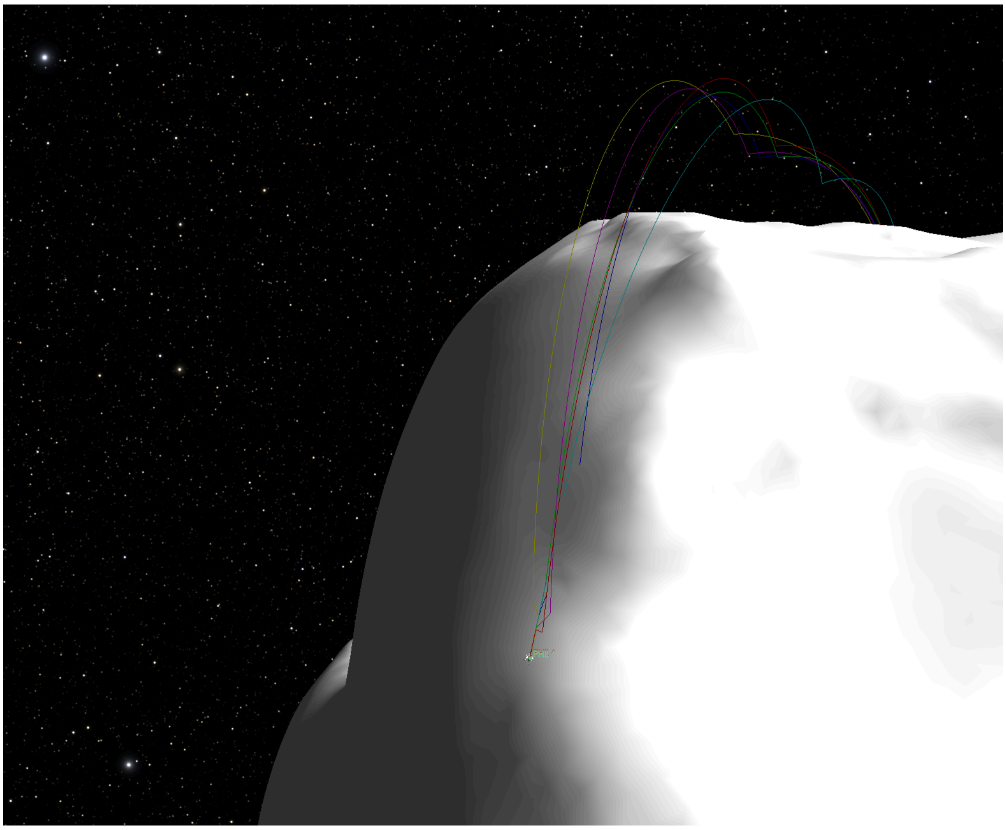
The following graphs show the three Euler Angles for both SDL kernels:

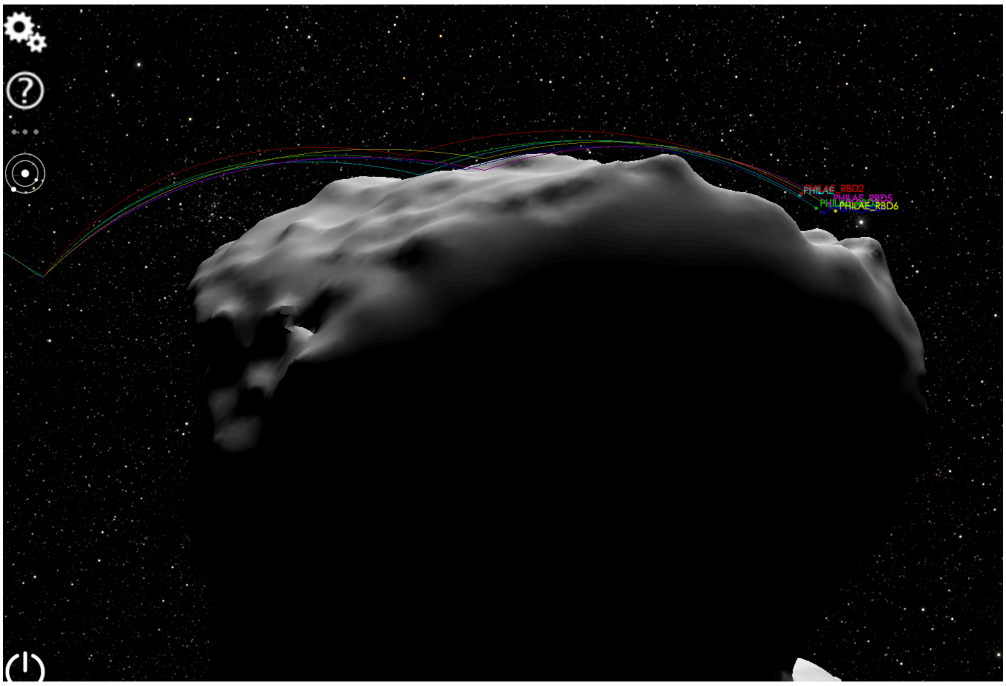

Euler Angles for LATT_EME2LDR_SDL_V1_0.BC
Euler Angle 1
150
100
50
0
-50
-100
-150
Euler Angles for LATT_EME2LDR_SDL_V1_0.BC
2014-11-12 11:00:00
2014-11-12 12:00:00
2014-11-12 13:00:00
2014-11-12 14:00:00
2014-11-12 15:00:00
Date in TBD

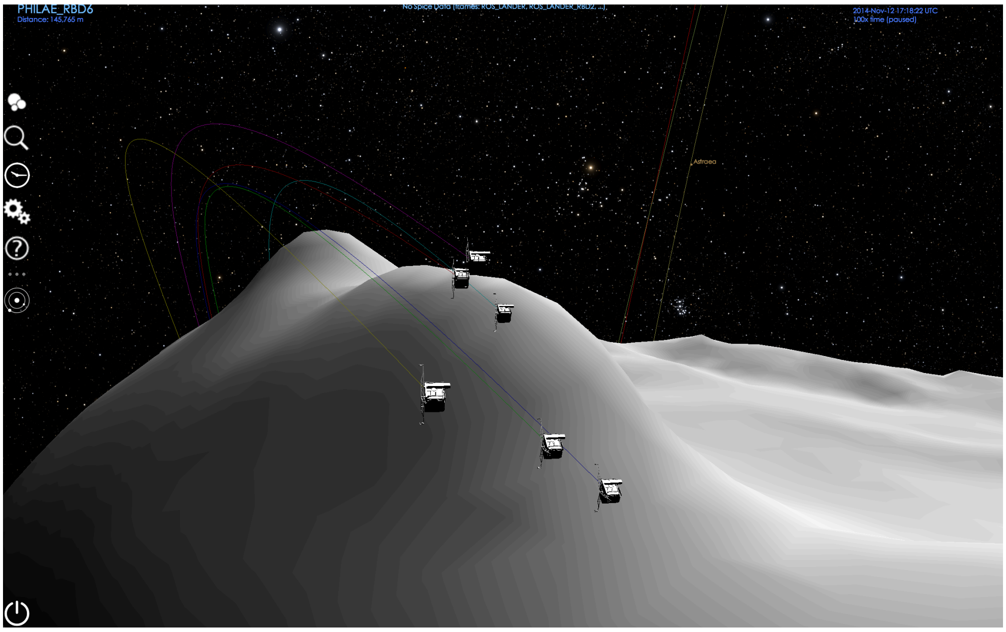


6.3 Best candidate for RBD trajectory

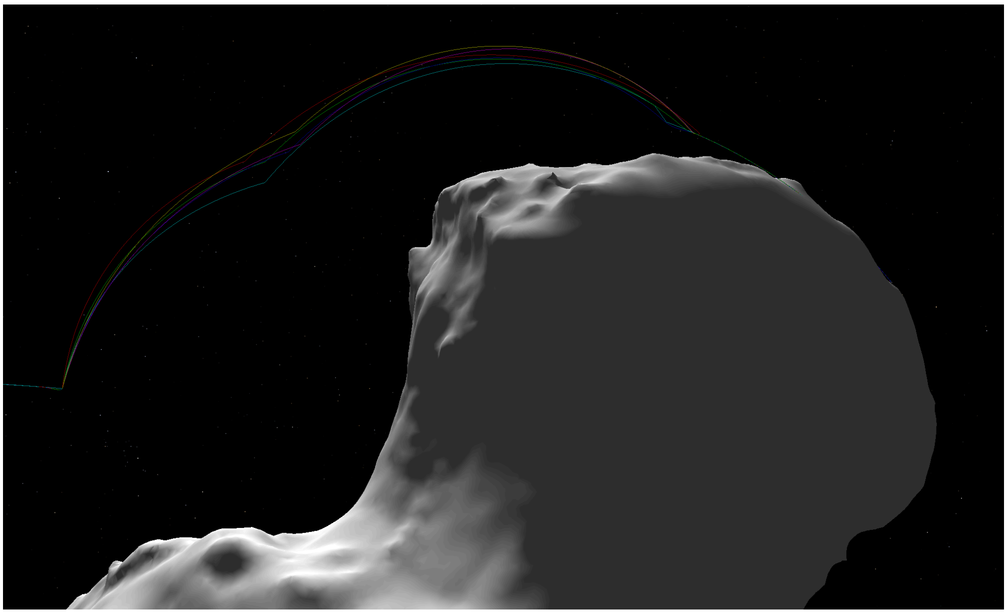
As described in Section 3.2 **there are six candidates for the RBD. None of them can be distinguished as a preferred solution**. It is important to note that the RBD trajectory has not been re-generated after OSIRIS revealed the final Lander location. In principle that is not a major issue since the last rebound is not modeled either hence in the context of the current data, this would not improve the current situation. In order to assess the best canidadte for RBD trajectory, a thorough study should be performed examining NAVCAM and OSIRIS images. Using the SPICE-Enchanced Cosmographia Tool might be helpfull. The following Figure illustrate six "Landers", one for each RBD candidate trajectory:




PHILAE_RBD2
PHILAE_RBD5
PHILAE_RBD6



A first visual inspection leads to believe that RBD candidate 4 is the most appropiate one since it is the one that fits best the final lander location as the following figure suggests (RBD 4 is in Blue):



Please note that this should not be considered as a conclusion by any means.