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Research and Science Support Department
Planetary Missions Division

ROSETTA - CONSERT

Archive User Guide

RO-OCN-UG-3870

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Change Log

Date	Sections Changed	Reasons for Change
22/01/2019	All	First issue
19/02/2019	All	ESAC review

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1 Introduction

1.1 Purpose and Scope

The CONSERT instrument on-board both Rosetta orbiter and its lander Philae is a bi-static radar. Its main objective was to perform deep interior sounding of the 67P/Churyumov-Gerasimenko comet nucleus.

The observational data retrieved from CONSERT operations in comet nucleus proximity were calibrated, collected and stored as archive data. Those archive data sets were prepared by SONC/CNES and CONSERT/IPAG with the support of PSA/ESAC and PDS/NASA.

This document is intended to provide a synthetic overview of the scientific data made available by the CONSERT experiment, and a quick explanation on how to access these high level data provided within the Planetary Science Archive (PSA/ESAC) and at PDS/NASA.

1.2 Contents

The document firstly gives the main information on CONSERT experiment and high level technical description of the instrument. CONSERT instrument being a unique payload of its kind, it is important that the user will get a clear understanding of the instrument general functioning.

In a second part, the main scientific operations are listed and described, to provide an overview of which data is available for science purposes.

And finally, an example of using the data in a practical way is given.

1.3 Intended Readership

Any potential user of the CONSERT scientific data.

1.4 Applicable Documents

[AD 1] RO-OCN-IF-3800, CONSERT EAICD, V4.1, 07/11/2018
[AD 2] RO-OCN-TN-3825, CONSERT User Manual, V0.10, 26/10/2017

1.5 Reference Documents

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[RD 2] Kofman, W., Herique, A., Goutail, JP. et al., "The Comet Nucleus Sounding Experiment by Radiowave Transmission (CONSERT): A Short Description of the Instrument and of the Commissioning Stages", Space Sci Rev (2007) 128: 413. https://doi.org/10.1007/s11214-006-9034-9

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[RD 5] A. Herique, W. Kofman, P. Beck, L. Bonal, I. Buttarazzi, E. Heggy, J. Lasue, A. C. Levasseur-Regourd, E. Quirico, S. Zine; Cosmochemical implications of CONSERT permittivity characterization of 67P/CG, Monthly Notices of the Royal Astronomical Society, Volume 462, Issue Suppl_1, 16 November 2016, Pages S516–S532, https://doi.org/10.1093/mnras/stx040

[RD 6] O. P. Pasquero, A. Hérique and W. Kofman, "Oversampled Pulse Compression Based on Signal Modeling: Application to CONSERT/Rosetta Radar," in IEEE Transactions on Geoscience and Remote Sensing, vol. 55, no. 4, pp. 2225-2238, April 2017.doi: 10.1109/TGRS.2016.2639449

[RD 7] Yves Rogez, Pascal Puget, Sonia Zine, Alain Hérique, Wlodek Kofman, Nicolas Altobelli, Mike Ashman, Maud Barthélémy, Jens Biele, Alejandro Blazquez, Carlos M. Casas, Marc Costa Sitjà, Cédric Delmas, Cinzia Fantinati, Jean-François Fronton, Bernhard Geiger, Koen Geurts, Björn Grieger, Ronny Hahnel, Raymond Hoofs, Armelle Hubault, Eric Jurado, Michael Küppers, Michael Maibaum, Aurélie Moussi-Souffys, Pablo Muñoz, Laurence O'Rourke, Brigitte Pätz, Dirk Plettemeier, Stephan Ulamec, Claire Vallat, The CONSERT operations planning process for the Rosetta mission, Acta Astronautica, Volume 125, 2016, Pages 212-233, ISSN 0094-5765, https://doi.org/10.1016/j.actaastro.2016.03.010.

[RD 8] Philip Heinisch, Hans-Ulrich Auster, Dirk Plettemeier, Wlodek Kofman, Alain Herique, Christoph Statz, Ronny Hahnel, Yves Rogez, Ingo Richter, Martin Hilchenbach, Eric Jurado, Romain Garmier, Thierry Martin, Felix Finke, Carsten Güttler, Holger Sierks, Karl-Heinz Glassmeier, Reconstruction of the flight and attitude of Rosetta's lander Philae, Acta Astronautica, Volume 140, 2017, Pages 509-516, ISSN 0094-5765, https://doi.org/10.1016/j.actaastro.2017.09.017.

[RD 9] L. O'Rourke, C. Tubiana, C. Güttler, S. Lodiot, P. Muñoz, A. Herique, Y. Rogez, J. Durand, A. Charpentier, H. Sierks, P. Gutierrez-Marques, J. Deller, B. Grieger, R. Andres, B. Geiger, K. Geurts, S. Ulamec, N. Kömle, V. Lommatsch, M. Maibaum, J.L. Pellon, C. Bielsa, R. Garmier, M. Taylor, P. Martin, M. Küppers, A. Accomazzo, V. Companys, J.P. Bibring, W. Kofman, S. Mckenna Lawlor, M. Salatti, P. Gaudon, The search campaign to identify and image the Philae Lander on the surface of comet 67P/Churyumov-Gerasimenko, Acta Astronautica, 2018, ISSN 0094-5765, https://doi.org/10.1016/j.actaastro.2018.12.035.

1.6 Acronyms and Abbreviations

AOCS	Attitude and Orbit Control System
BPSK	Binary Phase-Shift Key
CNES	Centre National d'Etudes Spatiales
CONSERT	COmet Nucleus Sounding Experiment by Radiowave Transmission
EAICD	Experimenter to Planetary Science Archive Interface Control Document
ESA	European Space Agency
ESAC	European Space Astronomy Center
FSS	First Science Sequence
I signal component	In-phase signal component
IPAG	Institut de Planétologie et d'Astrophysique de Grenoble
L2, L3, L4	Level 2, Level 3, Level 4 Archive products or data sets
LCN	Lander CONSERT unit
LTS	Long Term Science
NASA	National Aeronautics and Space Administration
OCN	Orbiter CONSERT unit
PDCS	PreDelivery, Calibration and Science
PDS	Planetary Data System
PSA	Planetary Science Archive
Q signal component	phase Quadrature signal component
RMS	Root Mean Square
S/C	Spacecraft
SDL	Separation, Descent and Landing
SNR	Signal to Noise Ratio
SONC	Science Operation & Navigation Center
TM	Telemetry

1.7 Contact Names and Addresses

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2 CONSERT experiment description

2.1 Science objectives

CONSERT is a bistatic radar instrument designed to provide information about the deep interior of the 67P/Churyumov-Gerasimenko comet nucleus by propagating long-wavelength electromagnetic waves between the lander Philae and the orbiter Rosetta [RD 1].

The proposed measurements contribute to our understanding of the composition and structure of the comet nucleus.

2.2 Instrument concept

An electromagnetic signal of about 3-m wavelength is transmitted from CONSERT on the Rosetta spacecraft in orbit around the nucleus. When CONSERT on the Philae lander located on the surface of the comet receives the signal, it transmits a second signal, which is, in turn, received by the orbiter. The time difference between transmitting and receiving the signal is carefully measured. It is a function of the relative position of Rosetta and Philae, but also depends on reflections and refractions within the nucleus. When the experiment was proposed in 1993 and according to understanding of the composition of cometary materials at that time, it was likely that propagation of electromagnetic waves of 3-m wavelength through the comet would be possible, so that a return signal would still be received even with Philae on the opposite side of the nucleus from the Rosetta orbiting spacecraft [RD 1].

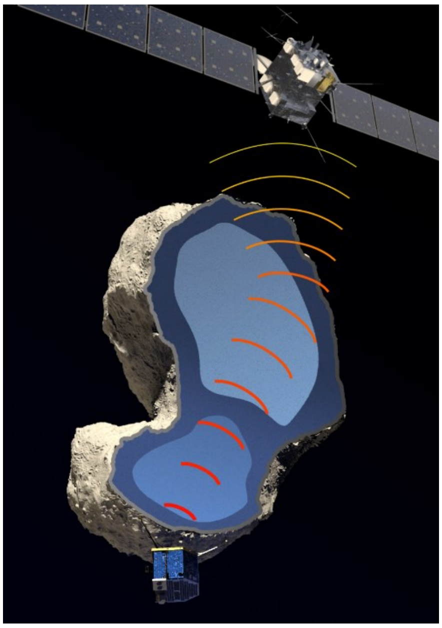

Figure 1 : CONSERT concept

The basic principle of the experiment is straightforward. An electromagnetic wave loses energy as it propagates through the cometary nucleus and travels at a smaller velocity than in free space. Both the actual amount of change in velocity and the energy loss depend on the complex permittivity of the cometary materials. They also depend on the ratio of the wavelength used to the size of any inhomogeneities present. Thus, any signal that has propagated through the medium contains information concerning this medium. As a result of a trade-off between the signal penetration, spatial resolution, antenna design, electronic speed, mass and power, we adopted a carrier frequency equal to 90 MHz, a bandwidth of 8 MHz and a sampling rate of 10 MHz (I and Q components). This bandwidth gives a resolution of 30 m in free space and less inside the comet nucleus, which is a satisfactory compromise between the scientific requirement and the technology. The major constraint, which is stability of the on-board clocks, led to the construction of the instrument working as a transponder in time between the Rosetta orbiter and the Philae lander [RD 1], [RD 2].

2.3 CONSERT payload description

The CONSERT instrument is composed of two units: one on-board the Rosetta orbiter spacecraft and one on-board the Philae lander. Each unit consists of an electronics box and an antenna device. OCN uses a crossed-dipoles antenna while LCN antenna are two orthogonally oriented monopoles located in front of Philae, in its x-y plane, parallel to the ground.

Complete instrument specifications are given in 6.1.

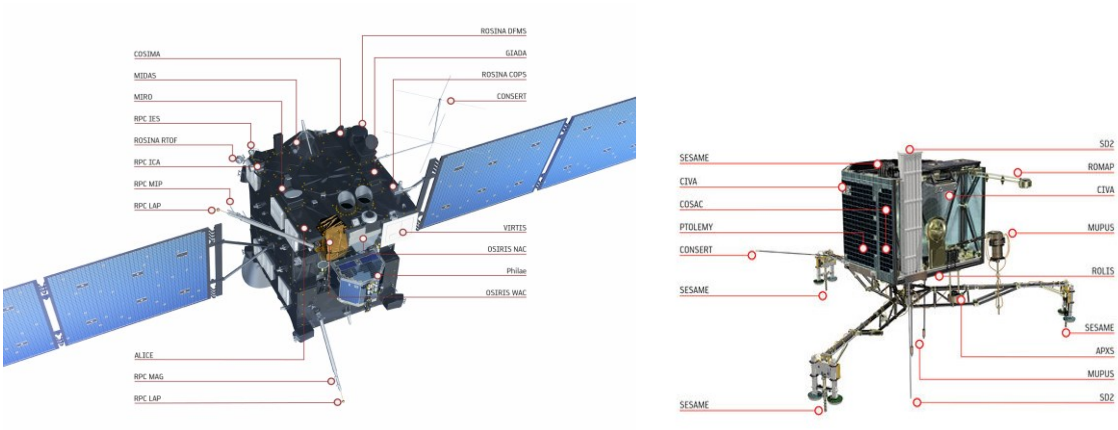

Figure 2 : CONSERT payload on Rosetta and Philae (Credit: ESA/Rosetta)

2.4 CONSERT technical description

The CONSERT instrument works as a time domain transponder between the lander unit and the orbiter unit. Basically, a 90 MHz sinusoidal waveform is phase modulated by a pseudorandom code or Phase Shift Keying Coding. Such frequency, in the radio range, is a trade-off between the losses during the propagation inside the comet material, the galactic noise, the bandwidth and the size of the antenna.

The basic measurement for CONSERT is the time delay along the propagation path between Philae and Rosetta. To retrieve valuable information on comet interior dielectric properties, this time measurement precision has to be better than 0.1 µsec, which leads to very high constraints in terms of clock frequency stability ($\Delta f/f = 10^{-12}$) for both lander and orbiter parts, as well as precise synchronization between clocks. This stability has to be assured during a complete CONSERT operation sequence: with margins, the required duration is typically 10h. This hard constraint is relaxed thanks to the transponder structure of the instrument. For each sounding, a first wave propagation is transmitted from OCN to LCN to synchronize the two devices. The signal is then mirrored by LCN to OCN in a second wave, along the exact same propagation path to perform the actual science measurement.

This requires a tuning phase at the beginning of the CONSERT sequence. The purpose of this phase is to synchronize the clocks of lander and orbiter CONSERT units by adjusting in frequency with $\Delta f/f < 10^{-7}$ and in time with Δt less than a few ms. The actual stability on the clocks is valid during 30h (*Figure* 3). In practice, this is achieved with a stabilized oven controlled crystal oscillator Sorep EWOS513.

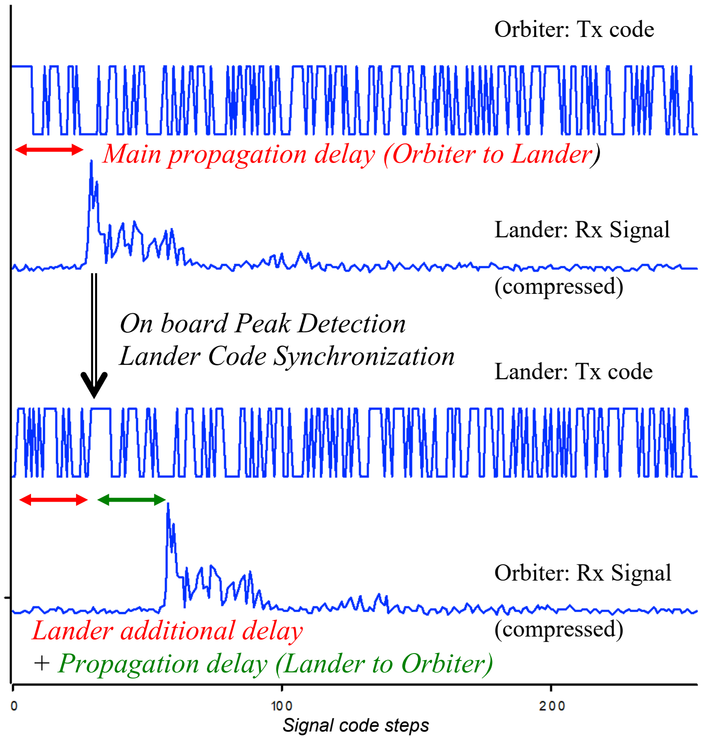

Figure 3: Lander synchronization principle [RD 2].

After the tuning phase, during the science measurement (or “sounding”) phase, the two units work autonomously until the end of the sequence. For a single measurement point in this sequence, the sounding cycle is: OCN transmits the signal and LCN listens and then LCN receives the signal, processes it and transmits a new signal back when OCN listens. To improve the signal to noise ratio, OCN and LCN units actually listen for 1024 signals and perform a coherent integration in addition to the signal compression. This “ping-pong” cycle is repeated typically every 2.5 s [RD 7].

2.5 Operation sequence

A complete CONSERT operation sequence is composed of the following phases (*Figure 4*):

- Warming up: the instrument needs some time to obtain the right functioning temperature allowing the appropriate clock stabilization.
- Tuning: this critical phase, mandatory after the warming up, needs a direct signal between the orbiter and lander allowing for the frequency of both clocks to be matched and for the synchronization of both calendars.
- Waiting: as the instrument is ready to work, it waits until occultation between lander and orbiter, to perform the science measurements.
- Science sounding: during this phase the signal between orbiter and lander needs to go through the comet nucleus. As each individual sounding (typically every few seconds) gives only information integrated along the ray, the most efficient observation will need to cross as much as possible of the comet section. In addition, observations at grazing angles allow information to be obtained regarding the roughness and layering at ground level

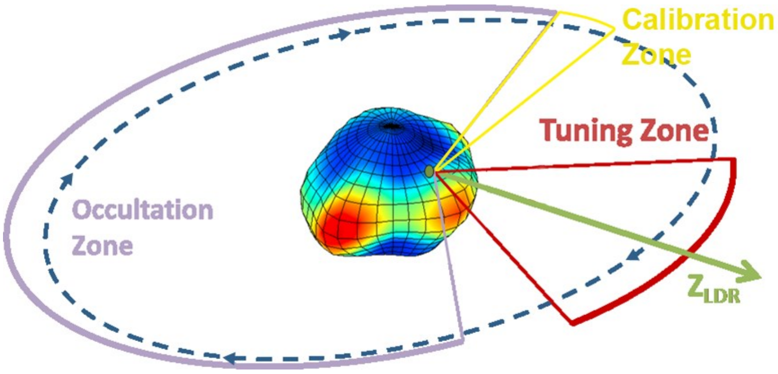

Figure 4: CONSERT science sequence.
Rosetta orbit is shown by the blue dashes. Lander Z axis (Z_{LDR}) vector shows the typical lander 'up' axis and position. Warm-up and tuning occur when Rosetta and Philae are in visibility, in the tuning zone (red), science sounding in the occultation zone (purple). Calibration takes place just after exiting the occultation zone (yellow). As a remark, this picture presents the preliminary shape model that was used before Rosetta arrived to 67P/C-G.

2.6 In-operation calibration

In addition, an optional calibration might be done, in continuity after the science sounding; these measurements will allow a better processing of the CONSERT science data. By acquiring the signal during the visibility period, just next to the science measurement phase, we can evaluate the Lander additional delay (
Figure 3) with comparable thermal and measurement conditions as the sounding. It is useful also to characterize the current noise background at acquisition time. The amplitude of the received signal is also determined by the CONSERT antenna properties: each CONSERT unit on lander and orbiter has its own antenna system with its gain and polarization properties.

2.7 CONSERT signal description

2.7.1 CONSERT compressed signal

The CONSERT measurements consist of a sequence of soundings: "there and back" travelling of the radar signal also called "ping-pong". Typically, they are sent every 2 to 5 seconds. This time scale along the orbit is referred as the radar "long time". A single sounding lasts in the order of tens to hundred μs depending mostly on the orbiter distance to the observed body. This time scale is referred as the radar "short time". This signal is recorded in a cycling window of 25.5 μs.

For every sounding, we have one signal received on the lander and another received on the orbiter. For data volume saving reasons, the full signal on the lander cannot be send to the ground segment through Rosetta for each sounding. Thus, there's an instrument setting ("FIOW") that defines the soundings interval between full (always named "long") signals on LCN which consist of 255 complex samples. Each sample have two components: I for in-phase and Q for quadrature component.

When a long signal is not sent to telemetry (TM) on LCN, it is replaced by a shorter one. This reduced "short" signal consists of 21 complex samples (also I and Q components). Contrary to the long signal, the short is compressed with the BPSK coded matched filter onboard LCN before submission to TM. The 21 samples are centered on the transponder detected peak. In all the cases each sample, or code step, corresponds to 0.1 μs.

2.7.2 CONSERT interpolated signal

The signal retrieved from the TM is then processed on-ground to output the final scientific signal data, using a specific interpolation algorithm [RD 6]. This interpolated signal is compressed and over-sampled by a factor of 20.

2.8 On-ground calibration

Below are the calibration processes preformed on CONSERT measurements. For details, please refer to [AD 1] EAICD, section 5.2.

- OCN and LCN long compressed signals
- Interferences cancelation
- Long time calibration (calibration of precise sounding times along the orbit)
- Amplitude calibration

For information, those processing steps have been stored in CONSERT L3 archive products.

2.9 On-ground processing

Below are the calibration and post-processes preformed on previously calibrated CONSERT measurements. For details, please refer to [AD 1] EAICD, section 6.1.

- OCN and LCN signal interpolation
- Short time (wave propagation time scale) calibration: transponder and system delay compensation, LCN jitter and peak detection correction
- Travel time determination (taking into account orbitography and short-time calibrations)
- Signal repositioning: the most powerful detected peak is placed at ¼ of the signal window
- Signal amplitude normalization

The final results of these processes have been stored in CONSERT L4 archive products and constitute the final data sets for this experiment.

2.10 CONSERT archive data sets

The complete CONSERT archive is composed of a series of datasets at different levels:

- Level 2: edited data from raw telemetry, including HK and AOCS
- Level 3: calibrated data including processing as described in 2.8
- Level 4: interpolated data as described in the present document

For each level, data sets have been archived for science data (which is focused in this document), but also for calibration & test data in flight (mostly during Cruise and PHC phases) and on-ground (during the Rosetta integration). All those available data sets are listed in [AD 1] EAICD, section 4.3 (Level 2), 5.5 (Level 3) and 6.4 (Level 4). The Ground calibration data sets include both the tested instrument telemetry and the measurements as taken by the laboratory equipment (also called the lab bench) which rely on a specific format.

2.11 CONSERT Level 4 data description summary

For the end user interested in scientific analyses of the CONSERT data, the CONSERT Archive Level 4 products are of best interest.

The compressed and interpolated signal data are available in the DATA directory of L4 archive.

FILE NAMING	DATA TABLE NAME	DESCRIPTION
CN_O_4_{date}.LBL/DAT	I_LONG_COMP_TABLE	OCN interpolated compressed signal – In-phase component
	Q_LONG_COMP_TABLE	OCN interpolated compressed signal – in Quadrature component
CN_L_LONG_4_{date}.LBL/DAT	I_LONG_COMP_TABLE	LCN interpolated compressed long signal – In-phase component
	Q_LONG_COMP_TABLE	LCN interpolated compressed long signal – in Quadrature component
CN_L_4_{date}.LBL/DAT	I_SHORT_TABLE	LCN interpolated compressed short signal – In-phase component
	Q_SHORT_TABLE	LCN interpolated compressed short signal – in Quadrature component

the {date} is given in a {YYYYMMDDT**hhmmss} format.*

Table 1 : L4 data files description

The main parameters available in the OCN CARAC_TABLE are listed below. A complete description can be found in [AD 1] EAICD, section 6.5.1.

PARAMETER	DESCRIPTION
O_SN	The CONSERT orbiter sounding number. A unique number starting at 0 and incremented by 1 identifies each sounding.
L_SN	The corresponding CONSERT lander sounding number. A unique number starting at 0 and incremented by 1 identifies each sounding. It can occur that a sounding is missing in the data, the correspondance between O_SN and L_SN allows to have a correct matching between OCN and LCN data.
UTC	The corrected UTC timing of each sounding given as a character string.
CN_SECONDS	The relative number of seconds from CONSERT instrument start-up.
CHANNEL_LOSS	The channel loss is the amplitude factor in instrument's unit after the calibration.
TOA	The final Time-of-Arrival, or propagation time, in µs, including all the corrections. This parameter is composed of three components for each sounding, to allow the detection of the three first peaks. If no significant peak was detected, the missing value -1 is set.
PEAK_POWER	The power in instrument unit dB scale, corresponding to each TOA. It is also composed of three components for each sounding.
QUALITY	For all the CONSERT sequences but FSS, as the quality of the signal was good, the flag is always set to 0. This parameter has been specifically analyzed and qualitatively defined for data taken during the FSS phase, as these science measurements are the most important ones for CONSERT. Please refer to [AD 1] EAICD for the detailed definition of the QUALITY flag.

Table 2 : L4 archive data main parameters

3 CONSERT observations

3.1 Overview

CONSERT has operated successfully during its nominal observation sequence. This took place just after the Philae landing on the comet nucleus surface. This observation is named the Philae's First Science Sequence (FSS) in the Rosetta operations process. Due to the unexpected landing configuration of Philae [RD 9], any other observation during Philae's Long Term Science (LTS) has not been possible.

However, at the end of FSS, some CONSERT operations have been performed in support of the Philae localization campaign [RD 4]. These are stated as "FSS Ranging" operations in the archives and were performed in visibility between Philae and Rosetta CONSERT units. These particular data are not covered in this document.

Two other observations can be of interest for the scientist wiling to exploit CONSERT data: Philae's Separation, Descent and Landing (SDL) phase, during which Philae left Rosetta to land on the comet nucleus, (described below), and also the PreDelivery Calibration and Science (PDCS) phase, during which CONSERT made calibration measurements in proximity of the comet nucleus surface. There was an attempt to get the surface reflected response in the signal but unfortunately, none has been detected in the acquired data.

PHASE	START TIME	STOP TIME
PDCS	2014-10-16T11:08:08	2014-10-16T13:51:07
SDL	2014-11-12T08:30:04	2014-11-12T14:51:36
FSS	2014-11-12T18:56:40	2014-11-13T05:41:10

3.2 Separation Descent and Landing (SDL)

The SDL operation for CONSERT was designed with the primary objective of supporting the Philae operations during the landing. By exchanging signal between Philae and Rosetta, CONSERT was able to monitor the distance between the two units. It also helped the attitude reconstruction of Philae during this phase.

At the end of the acquisition sequence, when Philae is close enough to the surface, the reflected signal on the surface becomes strong enough to be detectable, and is of interest for science analysis of the comet surface dielectric properties.

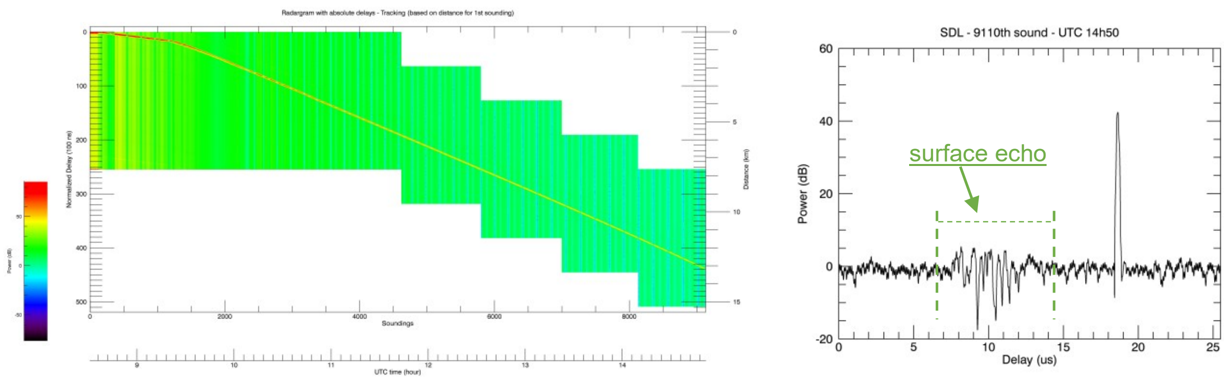

Figure 5 : CONSERT SDL direct signal along all trajectory (left) and a single sounding with surface echo (right)

3.3 First Science Sequence (FSS)

The FSS operation was the nominal operation for CONSERT. It contains the unique information about comet nucleus interior properties. The unexpected configuration of Philae after its chaotic landing degrades the quality of the CONSERT signal when propagating in the deepest part of the nucleus. Nevertheless, good measurements have been acquired in the beginning and end of this phase. These two phase are generally addressed as “evening” (of the 12nd November 2014) and “morning” (of the 13rd November 2014) CONSERT science data.

Figure 6 to Figure 8 show an overview of this data, as used for CONSERT scientific analyses in [RD 3], [RD 5].

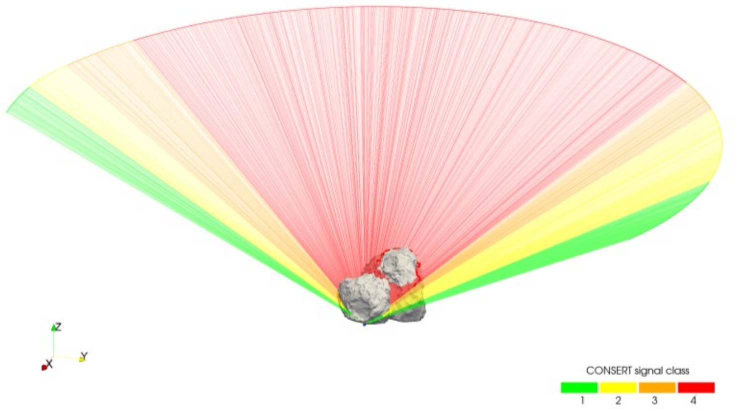

Figure 6 : CONSERT FSS science measurements overview

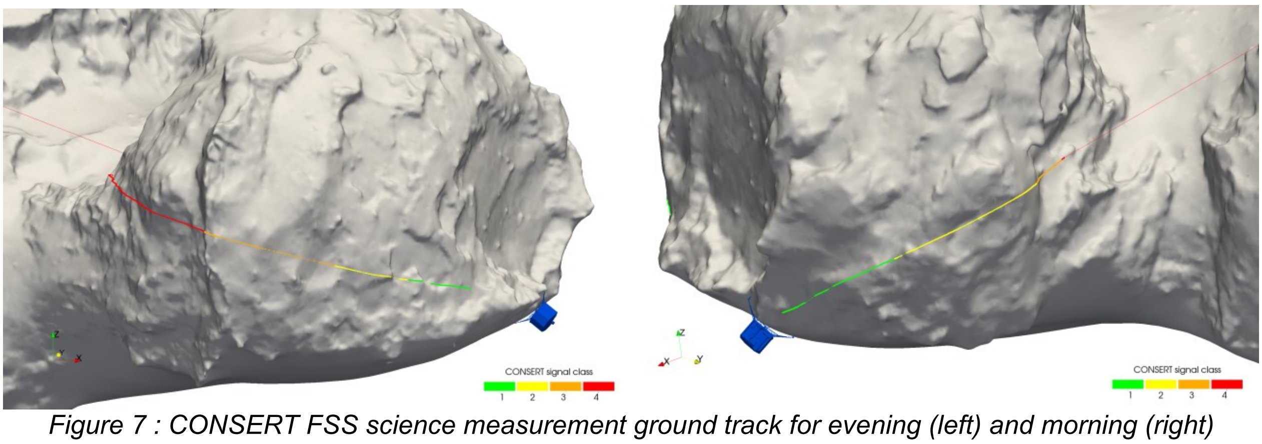

Figure 7 : CONSERT FSS science measurement ground track for evening (left) and morning (right)

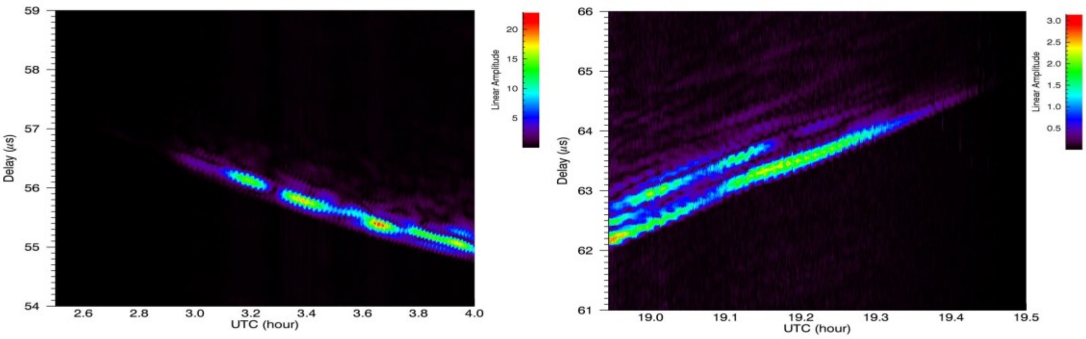

Figure 8 : CONSERT signal for evening (left) and morning (right)

SIGNAL CLASS	OCN SOUNDING NUMBER	UTC TIME OF BEGINNING	UTC TIME OF ENDING	DURATION
1	9158	12/11/2014 18:56:40	12/11/2014 19:28:28	00:31:48
2	9922	12/11/2014 19:28:30	12/11/2014 19:44:58	00:16:28
3	10318	12/11/2014 19:45:00	12/11/2014 20:13:25	00:28:27
4	11001	12/11/2014 20:13:27	13/11/2014 00:44:59	04:31:35
3	17518	13/11/2014 00:45:02	13/11/2014 01:21:09	00:36:10
2	18386	13/11/2014 01:21:12	13/11/2014 02:27:45	01:06:33
1	19984	13/11/2014 02:27:47	13/11/2014 04:05:45	01:37:58

Table 3 : CONSERT FSS signal quality classification

The signal quality classification presented in Table 3 gives an indication on the strength of the CONSERT signal peak by regard to the noise level (cf. [AD 1] EAICD, section 6.2.1) :

- 0: Strong signal with good LCN/OCN transponder synchronization, usable for travel-time analysis
- 1: Positive SNR but no transponder synchronization
- 2: SNR close to 0 dB (statistical detection)
- 3: No signal detected.

4 Recommendations and possible pitfalls

4.1 Amplitude and polarization

During the main scientific observation, the FSS, CONSERT operated with an unexpected Philae landing configuration. The LCN antenna has an unknown relative position with respect to the ground, and the local environment is largely still unknown or impossible to model with enough accuracy. Because of this, the antenna patterns are not well known and the complete and actual link budget cannot be evaluated for CONSERT.

This makes the amplitude and polarization analysis very difficult, if not impossible.

4.2 Instrument system and calibration

4.2.1 Time of arrival evaluation

The time of arrival, i.e. the propagation time of the radar wave between Philae and Rosetta CONSERT units, have been evaluated in L4 data taking carefully into account all calibration and corrections of the instrument system. It is given as the end product of the CONSERT experiment and is the result of a very complete and deep understanding of the instrument functioning. Details on what is done can be found in [AD 1] EAICD.

Re-evaluating this from very raw data should be done very carefully because of the uniqueness of CONSERT instrument.

4.2.2 Signal Modulo

Due to the instrument concept, the signal is measured in a window modulo of 25.5 µs. This should always be kept in mind when analyzing the CONSERT signal data.

4.3 Observation geometry considerations

4.3.1 Geometry data

The geometry data, which gives to the user an easy access to Rosetta and Philae relevant orbitography (position and attitude) for CONSERT observations, are given at the moment of the data product delivery and are not updated if the geometry itself is improved at a Rosetta or Philae level. Geometry source information has been taken from officially released Rosetta Spice kernels. The list of Spice kernels used for each dataset is given in its corresponding label (LBL) file using the SPICE_FILE_NAME keyword.

Although we do not expect significant modification of this information, we recommend the user to check their hypothesis carefully, especially concerning Philae's position during FSS.

4.3.2 Shape model and Philae location

When interpreting CONSERT data, one may want to use a shape model along with Rosetta and Philae orbitography information. It is of particular importance to carefully validate the hypothesis on Philae location on the surface model. Indeed, given latitude and longitude values can differ by several tens of meters when projected on one shape or to another. Secondly, when using Cartesian coordinates, one must ensure the coordinate system is consistent with the shape model, and that Philae is actually correctly placed on the surface. Moreover, it should be verified that the vicinity of Philae local area corresponds to the one imaged by OSIRIS camera in the last phase of the Rosetta mission.

4.4 Signal data considerations

4.4.1 Amplitude normalization

The CONSERT signal in L4 data are normalized sounding per sounding. Thus, the signal maximum inside a sounding is always 1.0. The normalization factor used for each sounding is given by the parameter NORM_FACTOR.

4.4.2 Peak repositioning

In the L4 CONSERT data, the interpolated signal has been circularly shifted inside each sounding recording window in such a way that the most powerful peak is positioned at the quarter of this window. During the FSS, by moment, two peaks are visible on the signal and the most powerful one can change from one to the other, which leads to some apparent signal jumps from sounding to sounding.

Please note that you can undo this circularization, as explained in this document, section 5.5 and [AD 1] EAICD, section 6.5.1.4.1.

4.4.3 Entropy parameter

An “Entropy” parameter is given for each CONSERT signal. It is a measurement of the signal quality ranging from -infinity to 0 in dB (0 to 1 in linear scale).

Signals with high signal to noise ratio correspond to low entropy (Pmax >> P var). Entropy can be down to -55 dB, corresponding to the actual sensitivity limitation from the plateau of the compressed BPSK code, after all on-ground processing applied. Signals with low signal to noise ratio correspond to an entropy close to 0. In practice, it is around -15 dB, corresponding to the power ratio between the maximum and the RMS of 255 samples of pure noise.

4.4.4 Ancillary and housekeeping data

Rosetta and Philae ancillary data that can be of interest for CONSERT data analysis (e.g. solar panel angle, high gain antenna position, ...) have been stored in the associated ancillary AOCS files. They are available in the L4 data sets with naming CN_A_4_*. A complete description is available in the label files and in [AD 1] EAICD, section 6.5.1.4.4.

One can also find instrument internal housekeeping information (e.g. currents, temperatures, clock frequencies, instrument statuses…) in the L3 data sets. Details can be found in [AD 1] EAICD, section 5.6.14.

5 CONSERT data usage

5.1 Introduction

In this section we will focus on FSS evening data and plot basic information that can be extracted from L4 CONSERT archives, V1.0. We will only use OCN data as it is of main interest, but LCN is quite similar in terms of usage.

The program snippets are using Harris/IDL syntax, but this can be achieved with any language with PDS format reading capability. In that sense, for IDL, you will have to retrieve and install the ReadPDS (for PDS3) library from PDS website (https://pdssbn.astro.umd.edu/tools/tools_readPDS.shtml) in order to execute the following examples.

5.2 Data of interest

First, we read the files containing FSS CONSERT orbiter science data.

```
FSSdata = readpds( "RORL-C-CONSERT-4-FSS-V1.0\DATA\CN_O_4_20141112T185640.LBL" )
```

Then, we select the “evening” period, using the sounding number OCN = [9158 ; 9922]

```
OSN = FSSdata.CARAC_TABLE.COLUMN1
```

Here, IDL has loaded the content of the data file (.DAT) linked to the given label file (.LBL) and has stored all the data tables into the structure variable named FSSdata. This structure is organized as follows:

FSSDATA	-> <Anonymous> STRUCT[1]
CARAC_TABLE	-> <Anonymous> STRUCT[1]
COLUMN1	FLOAT[15468]
COLUMN10	FLOAT[15468]
COLUMN11	DOUBLE[15468]
COLUMN12	DOUBLE[15468]
COLUMN13	FLOAT[15468]
COLUMN14	DOUBLE[3, 15468]
COLUMN15	DOUBLE[3, 15468]
COLUMN16	FLOAT[15468]
COLUMN17	DOUBLE[15468]
COLUMN2	FLOAT[15468]
COLUMN3	STRING[15468]
COLUMN4	DOUBLE[15468]
COLUMN5	FLOAT[15468]
COLUMN6	DOUBLE[15468]
COLUMN7	FLOAT[15468]
COLUMN8	FLOAT[15468]
COLUMN9	FLOAT[15468]
NAMES	STRING[17]
I_LONG_COMP_TABLE	-> <Anonymous> STRUCT[1]
OBJECTS	3
Q_LONG_COMP_TABLE	-> <Anonymous> STRUCT[1]

Figure 9 : L4 data structure with IDL

As shown in Figure 9, this structure contains a CARAC_TABLE including 17 columns. Each column corresponds to one parameter of CONSERT L4 product (all these parameters are detailed in [AD 1] EAICD, section 6.5.1.4.1). The CARAC_TABLE.NAMES field contains the name of the parameter for each column. I_LONG_COMP_TABLE.COLUMN1 contains the real part of the OCN signal and Q_LONG_COMP_TABLE.COLUMN1 contains its imaginary part.

Then, in further steps of this tutorial, we will pick up and manipulate information inside this structure.

```
beginSounding = 9158
endSounding = 9922
beginIdx = ( where( OSN EQ beginSounding ) )[0]
endIdx = ( where( OSN EQ endSounding ) )[0]
```

Then we check begining and end UTC dates and time with the internal CONSERT clock information

```
UTC = FSSdata.CARAC_TABLE.COLUMN3
print, "Begin UTC: ", UTC[beginIdx]
print, "End UTC: ", UTC[endIdx]
CNTime = FSSdata.CARAC_TABLE.COLUMN4
print, "CONSERT elapsed seconds at beginning: ", CNTime[startIdx]
print, "CONSERT elapsed seconds at end: ", CNTime[stopIdx]
```

The result is:

```
Begin UTC: 2014-11-12T18:56:40.258
End UTC: 2014-11-12T19:28:30.415
CONSERT elapsed seconds at beginning:        37655.484
CONSERT elapsed seconds at end:        39565.641
```

Remark : One can notice that the begin CONSERT time is not 0, this is due to the fact that CONSERT was not switched OFF between SDL and FSS phases. So at the beginning of the FSS phase, the CONSERT internal clock indicates a time with the beginning of SDL as a reference start time.

5.3 Time of arrival

First, we retrieve time of arrival data, and we replace the missing values negative constants by a NaN (Not a Number) value, in order to display it in a better way.

```
TOA = FSSdata.CARAC_TABLE.COLUMN14
TOA[where( TOA LT 0.0 )] = !VALUES.D_NAN
```

Then we can plot the time of arrival for FSS evening, in µs

```
pTOA0 = plot( OSN, TOA[0, beginIdx:endIdx], 'r+' )
pTOA1 = plot( OSN, TOA[1, beginIdx:endIdx], 'g+', /OVERPLOT )
```

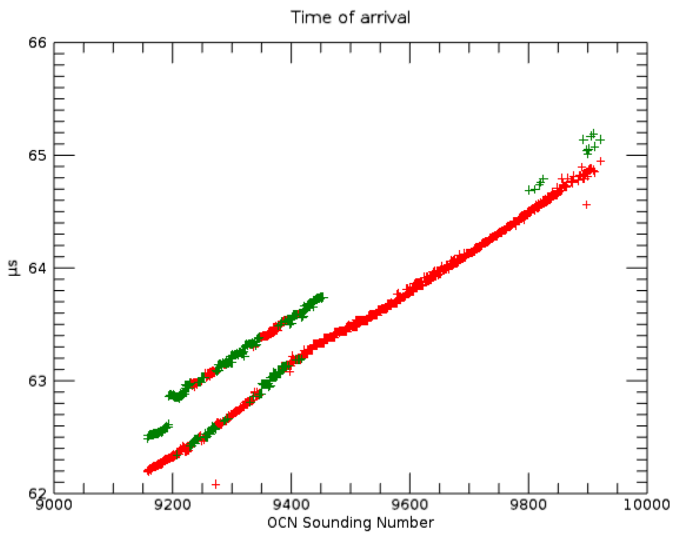

Figure 10 : FSS evening time of arrival

Remark: The time of arrival are sorted from most powerful to least powerful for each sounding in the TOA array. A missing value is put in place when no clear peak has been detected. In this particular case, all the third TOA peaks are missing, so we skip them.

5.4 Signal peak power

```
PeakPower = FSSdata.CARAC_TABLE.COLUMN15
PeakPower[where( TOA LT 0.0 )] = !VALUES.D_NAN
pPeakPower = plot( OSN, PeakPower[0, beginIdx:endIdx], 'r', TITLE='Peak power', XTITLE='OCN Sounding Number', YTITLE='dB' )
pPeakPower = plot( OSN, PeakPower[1, beginIdx:endIdx], 'g.', /OVERPLOT )
```

This plots the power in dB of the corresponding detected peaks

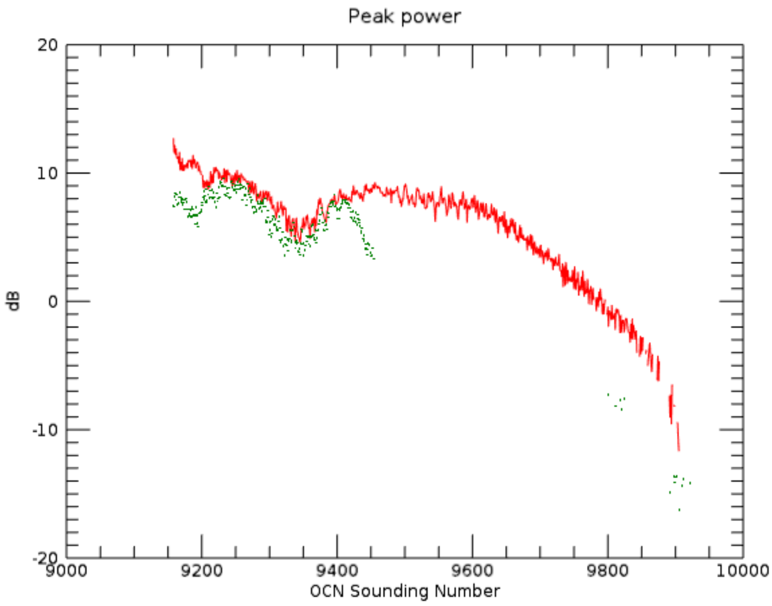

Figure 11 : FSS evening peak power

5.5 Sounding compressed signal

We read the entire signal data and immediately compute it in dB scale.

```
Signal = dcomplex( FSSdata.I_LONG_COMP_TABLE.COLUMN1, FSSdata.Q_LONG_COMP_TABLE.COLUMN1 )
dB_Signal = 20.0 * alog10( abs( Signal ) )
```

We will pick a single sounding at sounding #9400 and plot the signal, as given in the data.

```
soundingIndex = ( where( OSN EQ 9400 ) )[0]
p = plot( dB_Signal[*, soundingIndex], TITLE='Sounding 9400', XTITLE='Signal sample', YTITLE='dB' )
```

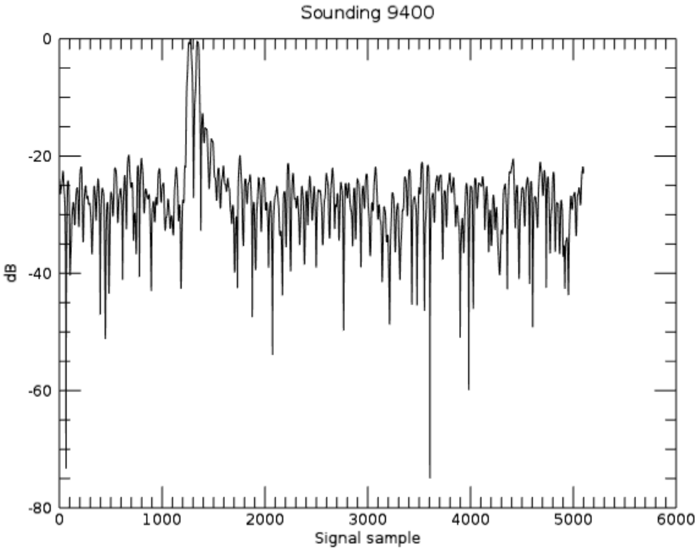

Figure 12 : FSS evening sounding #9400

We see on Figure 12 that the main peak is located at ¼ of the CONSERT signal window.

We now will replace the signal in its original position, before the circularization process.

```
TimeWindowFirstSample = FSSdata.CARAC_TABLE.COLUMN13
db_Signal_Uncirc = shift( dB_Signal[*, soundingIndex], -TimeWindowFirstSample[soundingIndex] )
p = plot( db_Signal_Uncirc, TITLE='Un-circularized Sounding 9400', XTITLE='Signal sample', YTITLE='dB' )
```

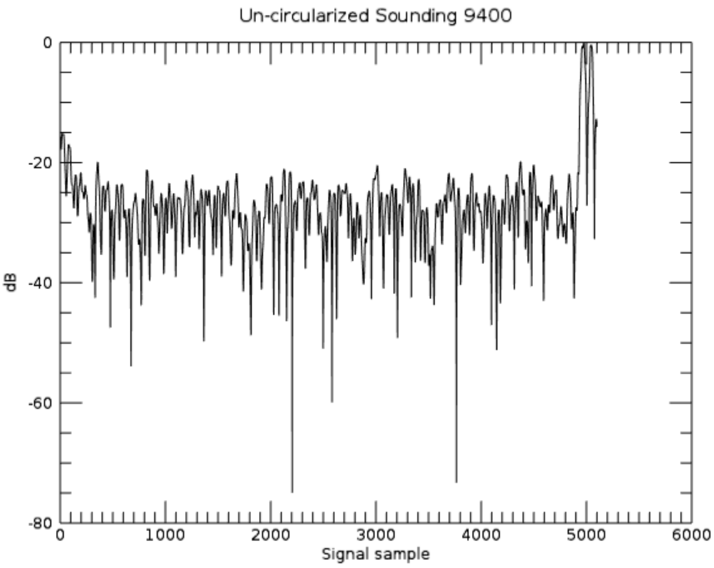

Figure 13 : FSS evening sounding #9400, de-circularized

And finally if we want a non-normalized signal, we have to re-apply the normalization factor to the linear signal, plotted in Figure 14.

```
NormFactor = FSSdata.CARAC_TABLE.COLUMN5
NbSamples = ( size( Signal ) )[1]
NbSoundings = ( size( Signal ) )[2]
Signal_NotNorm = Signal * transpose( rebin( NormFactor, NbSoundings, NbSamples ) )
dB_Signal_NotNorm = 20.0 * alog10( abs( Signal_NotNorm ) )
db_Signal_Uncirc_NotNorm = shift( dB_Signal_NotNorm[*, soundingIndex], -TimeWindowFirstSample[soundingIndex] )
p = plot( db_Signal_Uncirc_NotNorm, TITLE='Un-circularized un-normalized Sounding 9400', XTITLE='Signal sample', YTITLE='dB' )
```

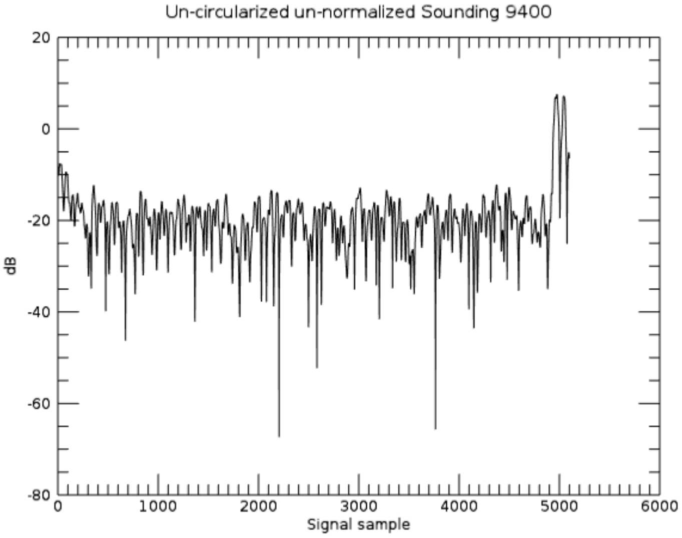

Figure 14 : FSS evening sounding #9400, de-circularized and de-normalized

5.6 Radargram

Now we can plot a full radargram of our selected period (Figure 15). To do so, we have to de-circularize all the soundings in a loop.

```
db_Signal_Uncirc_NotNorm = make_array( NbSamples, NbSoundings, /DOUBLE )
FOR soundingIndex = beginIdx, endIdx DO BEGIN
  db_Signal_Uncirc_NotNorm[*, soundingIndex] = shift( dB_Signal_NotNorm[*, soundingIndex],
-TimeWindowFirstSample[soundingIndex] )
ENDFOR
i = image( transpose( db_Signal_Uncirc_NotNorm[*, beginIdx:endIdx] ), $
           [beginSounding:endSounding], indgen( Nbsamples ), $
           XTICKINTERVAL=100, $
           TITLE='FSS evening radargram (dB)', $
           AXIS_STYLE=1, XTITLE='Sounding number', YTITLE='Signal samples', $
           RGB_TABLE=39, ASPECT_RATIO=0.1, MIN_VALUE=-15.0 )
cb = colorbar( ORIENTATION=1 )
```

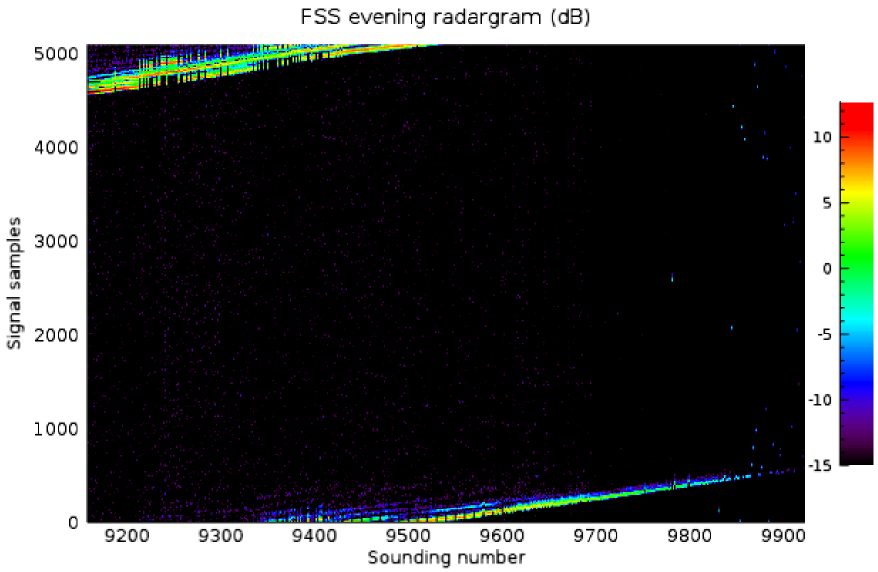

Figure 15 : FSS evening radargram

6 Annexes

6.1 Instrument specification

SPECIFICATION	VALUES
Mass	3 kg on Orbiter, 2.3 kg on Philae
Average power	3 W on Orbiter and on Philae
Peak power	11 W on Orbiter and on Philae
Clocks	10 MHz Sorep micro-OCXO (Oven Controlled Crystal Oscillator)
Nominal operation	$\Delta f / f < 2\ 10^{-7}$
Degraded mode if offset	$2\ 10^{-7} < \Delta f / f < 4\ 10^{-7}$
Transmission	90 MHz carrier, BPSK modulation
Pseudo noise code	255 × 100 ns = 25.5 μs
Code repetition	Up to 200 ms
RF power	2 W/Orbiter, 0.2 W/Lander
Receiver	Band 86–94 MHz (−3 dB), linear phase
Gain range	30–90 dB with AGC
Demodulation	I and Q “synchronous” detection
ADC	8 bits 10 MHz ADC on each channel
Processing	
Real time coherent integrations	1,024 code periods (26 ms, +30 dB on SNR) 256 periods (+24 dB on SNR), in degraded mode.
On-board the Lander	Code compression (+24 dB on SNR) and peak detection
Telemetry (data rate)	Orbiter: 8 kbits/measurement point ~ 65 Mbits/Orbit Lander: ~20 Mbits/Orbit (depending on how often the complete set of data will be transmitted)

Table 4 : CONSERT Instrument Specification

– END OF DOCUMENT –