The instrument link-up of Rosetta
Some SESAME lessons learned

Prepared by:

[1]Klaus Thiel
on behalf of the SESAME Team

[1]Nuclear Chemistry Department, University of Köln
klaus.thiel@uni-koeln.de

Applicable Documents

LSE-Interaction-TN_v4-2, 24. July 2006	RO-LSE-TN-3403 [TN-3403]

Document History

Issue/Revis.	Date	Description of Change
0/0	2016-06-03	Short oral presentation at the Philae get-together Conference, 1-3 June 2016, Budapest
1/0	2016-06-06	First draft script
1/1	2016-07-12	New text structure, details added
1/2	2016-07-28	Added corrections and comments of SESAME team members involved in SESAME instrument interlinking (PI, Flight S/W Development Team, CASSE & PP Team)
1/3	2016-08-04	Minor corrections

Distribution List

Recipient	Affiliation	E-mail address
Jean-Pierre Bibring	IAS Orsay	jean-pierre.bibring@ias.u-psud.fr
Hermann Böhnhardt	MPI for Solar System Research	boehnhardt@mps.mpg.de
Gerhard Schwehm	ESA / ESTEC Noordwijk	gerhard.schwehm@esa.int

Table of Contents

1 Scope of this Document

The present Technical Note summarizes some more general "lessons learned" by the Philae SESAME Team during the Rosetta Mission as outlined at the Philae get-together Conference, 1-3 June 2016, Budapest. The document deals with aspects of interlinking scientific instruments of the Rosetta Mission on hardware level with main focus on the Philae Lander. Based on examples of instrument link-up some conclusions and feasible future steps are deduced, which are meant as a rough copy of first thoughts, only. Aspects of "lessons learned" particularly concerning the SESAME instruments CASSE, DIM and PP will be summarized in more detail by a separate document.

2 LESSONS LEARNED - The case of Rosetta

2.1 Starting situation

Complex unmanned space missions often comprise a large number of instruments and tools. In the case of Rosetta about 20 independent science teams developed their specific instruments with the aim to make them function flawlessly under space conditions and to have them integrated at useful locations on the Orbiter or on the Lander.

The Rosetta spacecraft thus represented a tremendously powerful system of complex sensors and measuring devices capable of harvesting a huge amount of science data from a cometary nucleus. **Despite the capability of the instruments, the *optimum of the overall science return* could probably not be reached because options of intelligent link-up between the instruments had not been adequately considered.**

Scientific objective and design of each instrument generally was confined to the measurement of specific cometary phenomena or parameters, in most cases without the intention to interact with other instruments on hardware level. Such a situation only allows cooperation of different teams on a post-mission ***data evaluation level*** but not on an operational ***experiment level*** with *in situ* instrument interaction.

2.2 Lack of inter-instrument collaboration

Only a few exceptions of instrument link-up could be realized for the Rosetta Mission, e.g. using Orbiter and Lander on opposite sides of the comet to investigate the cometary interior by penetrating microwaves. For the 10 instruments on the Philae Lander, particularly SESAME/CASSE was able to initiate a successful cooperation with MUPUS on hardware level. Not successful for known reasons was the intended hardware link-up of the SESAME/PP instrument that was designed to take advantage of using parts of MUPUS and APXS as mechanical support for its electrodes.

An essential cooperation was achieved between RPC/MAG on the Orbiter and ROMAP on the Philae Lander, which allowed the reconstruction of Philae's motion during the descent until its final stop.

Interpretation of SESAME/PP passive measurements would be impossible without the plasma information from the RPC/MIP instrument. This close cooperation on data evaluation level was formalized by making the MIP PI also a Co-I of PP and *vice versa* early on in the mission.

A coordinated measurement between ROMAP and PP on experiment level with *in situ* instrument collaboration was planned for the LTS phase to determine the surface material's conductivity. Obviously, this measurement could never be realized, though even a LIOR already existed.

Interaction of SESAME with other Lander units was planned, as documented in the previous Technical Note RO-LSE-TN-3403 from 24. 07 2006 [TN-3403], but could not be successfully established due to circumstances discussed in the following sections.

Although the Lander Lead Scientists urgently appealed to all Lander Teams to look for options of inter-instrument measurements, no further collaboration could be set up.

2.3 Reasons for the lack of instrument link-ups

There are essentially two reasons for the difficulties to establish instrument interlinking for *in situ* co-measurements:

(1) Instrument hardware and the corresponding flight software are often designed to operate the respective instrument in a single-track manner without taking into account abilities and measuring techniques of other co-investigating instruments on the same spacecraft ("I am alone on board" philosophy).

(2) The hardware logistics on the spacecraft itself (in case of Philae: the supporting systems of the Lander) are not sufficiently prepared to provide e.g. fixed-wire direct hardware connections between the various scientific instruments. For the Lander this circumstance caused a rather severe handicap, namely the lack of a high precision hardware clock accessible by all instruments. Thus it was for example not possible to synchronize two instruments on a sub-millisecond timescale or to include sufficiently precise time stamps in corresponding telemetry data of two co-experimenting instruments.

One cause for the "I am alone on board" philosophy obviously is the fact that many instruments already successfully flew on some previous space missions, and greater changes in hardware and software of a "running system" are often avoided for time and financial reasons.

An example for providing clock time information down to the 1 *microsecond* level is ESA's JUICE Mission, where the plasma instrument PEP is sending *in situ* high resolution ion energy spectra with precise time information to the Radio and Plasma Wave Investigation instrument RPWI in order to have wave-particle interactions automatically calculated already on the mission spacecraft [Walter Schmidt; private communication, 05.06.2016].

2.4 Why was the SESAME – MUPUS collaboration successful?

The main reasons were:

(1) The Command and Data Management System (CDMS), which is one of the central instrument supporting systems of the Lander, provided some basic means to allow communication between any two Philae instruments already in the planning phase of the mission. CDMS features favouring SESAME – MUPUS cooperation have been:

(a) Fixed-wire electronic connections available between each Philae instrument and the CDMS
(b) Standardized data transfer procedures between each Philae instrument and the CDMS in both directions
(c) The existence of Backup RAM Buffers (BRAMs) of similar structural design for each instrument.

(2) Despite the fact that a high precision hardware clock was missing, at least the approximate start of *operation phases* of SESAME and MUPUS could roughly be synchronized on a millisecond timescale via tricky software workarounds. To synchronize *single measurements* of both instruments would have required a hardware clock on microsecond level or a direct hardware trigger line between both instruments.

(3) To allow data transfer between SESAME and MUPUS in both directions, the data format in the flight software of both instruments could easily be readjusted.

(4) In the specific case of the SESAME - MUPUS link-up various synergy effects could be achieved with a minimum of changes in the design of instrument hardware and software, which turned out to be a strong incentive for the cooperation of both teams.

(5) Working meetings of the respective team members and additional travelling expenses could be minimized since the necessary changes in the flight software of both instruments were mainly done by telecommunication.

(6) Joint hardware tests of SESAME/CASSE and MUPUS to verify the successful cooperation of both instruments could be performed using the respective Ground Reference Models (GRMs) and the GSE at DLR Köln, thus avoiding additional logistic efforts.

In other cases of instrument cooperation that had been proposed in the document of Technical Note [TN-3403], either instrument hardware implementation had already progressed too far, or necessary changes in the flight software design were too great.

2.5 Examples of instrument - spacecraft link-ups

Only *after* launch of the Rosetta spacecraft three options of cooperation between the SESAME/CASSE instrument and some components of the spacecraft itself (e.g. LMSS) became apparent, options that could not already be considered in document [TN-3403] for obvious reasons:

(1) It turned out that in the tandem flight configuration of Orbiter and Lander the SESAME/CASSE instrument was capable of detecting vibrations of the Orbiter Reaction Wheel. Frequency analyses of the sound emitted by the Reaction Wheel and measured by SESAME/CASSE allowed facilitating the necessary Reaction Wheel functional tests during mission flight.

(2) The same applies for the Philae Flywheel. Registering the flywheel vibration frequency at different speeds of wheel rotation SESAME/CASSE was a great help in Flywheel calibration.

(3) A challenge of vital interest was the definition of the moment of Philae's ground contact during the Separation, Descent and Landing Phase (SDL). The CASSE Piezo sensors in the soles of Philae's Landing Gear were obviously destined to generate a feasible touch-down signal. The CASSE measurements are essential in clarifying the complex landing event.

These cases of instrument - spacecraft interlinking were obviously inspired and supported by a close personal contact between scientists and engineers at DLR Köln.

3 LESSONS TO GIVE – Some conclusions

3.1 Overview

From the "lessons learned" outlined in chapter 2, a variety of conclusions may be deduced. **There are obviously some favourable conditions that should be fulfilled to enable a fruitful link-up between instruments on a spacecraft of complex research mission in order to accomplish an *optimum of the final overall scientific outcome*.**

These favourable conditions are certain *steps and items* in the planning phase of a multi-instrument space mission, which may affect planning sequence, finances, payload, and control of instrument integration on the spacecraft. Such steps and items may be implicitly presupposed also during many ESA and NASA missions, but may have not so fruitfully been applied in the course of the Rosetta Mission.

The mentioned prerequisites are listed again below and will be specified in more detail in chapters 3.2 to 3.6.

(1) *Planning phase of instrument interlinking* as early as possible (chap. 3.2)

(2) *Fund reserves* to allow for necessary extensions of the original single-instrument hardware and software (chap. 3.3)

(3) *Payload reserve* to allow for a possible payload mass increase due to instrument link-up (chap. 3.4)

(4) *Assessment of feasibility of instrument link-ups* on the spacecraft (chap. 3.5)

(5) *Sufficiently large time slot for calibration and tests of mutual interference of instruments* in their final configuration (chap. 3.6).

3.2 Early planning phase of instrument cooperation

To make point (1) of the above list an effective item, planning and design of instrument link-up should start at the earliest possible moment in time. Generally, one of the first steps in preparing a complex multi-instrument space mission is to invite all team representatives (e.g. PIs and specialists) to present their scientific objectives and describe their favourable scientific instrument that shall be implemented on the spacecraft.

Such working meetings and conferences obviously offer the chance to identify possible instrument interlinking in a very early stage of mission planning. The meeting agenda also should include the fixing of the selected prime contractor as early as possible.

In a final session of such meetings when objectives and design of all instruments have been presented, the science teams should be *explicitly* offered the opportunity of suggesting a possible cooperation between two or more teams by using instrument link-ups and co-measurements during the mission.

Options of cooperation should preferentially be considered before the hardware design is finalized on instrument and spacecraft level.

Cooperation will obviously be the more attractive the more scientifically relevant the achievable synergy effects *for both instrument teams* are. The inclusion of instrument team members as formal co-investigators in the cooperating teams could be helpful.

3.3 Fund reserves to allow for instrument link-up development

The cooperation between instrument teams may require the additional design and implementation of a specific interlinking hardware and/or software.

PIs and group leaders (as well as sponsoring institutions) therefore should provide adequate financial reserves for the purpose of developing instrument link-ups.

According to chapter 3.2 this project planning phase should also be completed well before hardware implementation of a given scientific instrument has been finalized.

3.4 Payload mass reserve to allow for additional hardware

Hardware of instrument link-ups may cause additional payload mass.

A budgeted payload reserve should allow slight upward shifts of the mission payload total mass limit.

3.5 Assessment of instrument link-up integration

Some kind of Steering Committee or other delegation of scientists and engineers should evaluate the proposed instrument link-ups and give an assessment of the link-up integration on the spacecraft with respect to

- complexity and risk of faulty function
- scientific relevance and achievement of synergy effects
- restriction and hindrance to measurements of the original instruments
- consumption of spacecraft resources
- expenditure of additional money, etc.

3.6 Time for instrument calibration and interference tests after integration

The calibration and interference status of instruments on Rosetta and other space missions showed how important a respective characterization of the instruments in their final configuration is, possibly influenced by the spacecraft structure and the activities of other instruments. A sufficiently large time slot should be allocated in the spacecraft development schedule to carry out these calibrations and instrument interference tests.

4 Summary

4.1 Final remark

There is one reason not mentioned in chapter 2.3, why planning of instrument link-ups for a multi-instrument space mission is not straightforward, but requires a somewhat contradictory planning sequence:

Mechanical and electrical support systems for scientific instruments on a spacecraft are generally planned and implemented in a very early phase of a space mission.

Design and implementation of the scientific instruments involved in that mission are carried out essentially in parallel or in a somewhat later mission stage.

Therefore, options of instrument link-ups can only be identified in a rather advanced planning stage. The subsequent design of instrument interlinking may however affect in turn the already completed preceding design of the mechanical and electrical support systems of the spacecraft, necessary to accomplish the interlinking.

In view of these somewhat contradictory planning conditions, instrument link-ups achieved during the Rosetta Mission have to be assessed still quite positive.

5 Appendix

5.1 List of Acronyms

APXS	Alpha-Proton X-Ray Spectrometer
BRAM	Backup Random Access Memory
CASSE	Comet Acoustic Surface Sounding Experiment
CDMS	Command and Data Management System
Co-I	Co-Investigator
DIM	Dust Impact Monitor
GRM	Ground Reference Model
GSE	Ground Support Equipment
JUICE	Jupiter Icy Moons Explorer
PI	Principal Investigator
LIOR	Lander Instrument Operation Request
LMSS	Lander Mechanical Support System
LTS	Long Term Science
MIP	Mutual Impedance Probe (part of RPC)
MUPUS	Multi-Purpose Sensors for Surface and Sub-Surface Science
PEP	Particle Environment Package
PP	Permittivity Probe
ROMAP	Rosetta Lander Magnetometer and Plasma Monitor
RPC	Rosetta Orbiter Plasma Consortium
RPWI	Radio and Plasma Wave Investigation
SDL	Separation, Descent and Landing
SESAME	Surface Electric Sounding and Acoustic Monitoring Experiment
S/W	Software