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Sorption Cooler Sub-System

Commissioning Phase Report

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TABLE OF CONTENTS

LIST of ACRONYMS **5**

APPLICABLE & REFERENCED DOCUMENTS **9**
Applicable Documents 9
Referenced Documents 9

1. Introduction **11**

2. Commissioning Activities **11**
2.1. Test Objectives 12
2.2. Test History 12

3. SCS COP Test Matrix **13**

4. COP Activities Results **13**
4.1. SCS Activation – P_COP/PVP_SCS_0001_01 13
4.1.1. P_COP/PVP_SCS_0001_01 results and Verification Matrix 14
4.2. SCS Compressor Tuning – P_PVP_SCS_0002_01 17
4.2.1. P_PVP_SCS_0002_01 results and Verification Matrix 17
4.3. SCS TSA Tuning – P_PVP_SCS_0003_01 and _02 18

5. Anomalies **20**
5.1. Bad Bed Detection Anomaly Report 20
5.2. Cold End Fluctuations 20

6. Lifetime **23**

7. Summary **23**

LIST of ACRONYMS

ACMS	Attitude Control Management System
AD	Applicable Document
AIV	Assembly, Integration and Verification
ASW	Application SoftWare
AVM	Avionics Verification Model
BEM	Back End Module (LFI)
BEU	Back End Unit (LFI)
BIN, bin	Binary
BOL	Begin of Life
CCE	Central Check-out Equipment
CCS	Central Check-out System
CDMS	Command and Data Management Subsystem
CDMU	Central Data Management Unit
CE	Compressor Element (Compressor Bed)
CIDL	Configuration Item Data List
CoG	Centre of Gravity
COP	Commissioning Phase
CPV	Calibration and Performance Verification
CQM	Cryogenic Qualification Model
CRC	Cyclic Redundancy Check
CSL	Centre Spatial de Liege
CTE	Coefficient of thermal expansion
CTR	Central Time Reference
DAE	Data Acquisition Electronics (LFI)
DC	Direct Current
DDS	Data Distribution System
DEC, dec.	Decimal
DMS	Documentation Management System
DPC	Data Processing Centre
DPU	(Data (or Digital) processing Unit
DS	Data Server
DTCP	Daily Telecommunication Period
ECR	Engineering Change Request
EEPROM	Electrically Erasable PROM
EGSE	Electrical Ground Support Equipment
EM	Engineering Model
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
EOL	End of Life
EQM	Engineering-Qualification Model
ESA	European Space Agency
ESD	Electro Static Discharge
ESOC	European Space Operations Centre
ESTEC	European Space Technology and Research Centre
FCS	Flight Control System
FDIR	Failure Detection, Isolation and Recovery
FEM	Front End Module (LFI)
FEU	Front End Unit (LFI)

FM	Flight Model
FMECA	Failure-Modes, Effects and Criticality Analysis
FOP	Flight Operations Plan
FPA	Focal Plane Assembly
FPS	Focal Plane structure
FPU	Focal Plane Unit
FS	Flight Spare
FTS	File Transfer System
GS	Ground Segment
H/W	Hardware
HEX, hex.	Hexadecimal
HFI	High Frequency Instrument (Planck)
HK	House Keeping (data)
HPFTS	Herschel-Planck File Transfer System
HPLM	Herschel Payload Module
IAP	Institut d'AstroPhysique
IAS	Institut d'Astrophysique Spatiale
ICD	Interface Control Document
ICWG	Instrument Coordination Working Group
ID	Identifier
IDT	Instrument Development Team
IID	Instrument Interface Document
IID-B	Instrument Interface Document - part B
ILT	Instrument Level Test
IOM	Instrument Operations Manager
IOT	Instrument Operations Team
IRD	Interface Requirements Document
IST	Integrated System Test
JPL	Jet Propulsion Laboratory
JT	Joule Thompson
kbps	kilobits per second
LCL	Latch Current Limiter
LEOP	Launch and Early Operations Phase
LFI	Low Frequency Instrument (Planck)
LGA	Low Gain Antenna
LL	Low Limit
LPSC	Laboratoire Physic Subatomic et Cosmologie
LSB	Least Significant Bit
LUT	Look Up Table
Mbps	Megabits per second
MCC	Mission Control Centre
MGSE	Mechanical Ground Support Equipment
MIB	Mission Information Base (database)
MLI	Multilayer Insulation
MOC	Mission Operations Centre
MoI	Moment of Inertia
MSB	Most Significant Bit
MTL	Mission Time Line
N/A, n.a.	Not Applicable
NaN	Not a Number
NCR	Non Conformance Report
NRT	Near-Real-Time
OATs	Osservatorio Astronomico di Trieste

OBCP	On-Board Control Procedure
OBSM	On-Board Software Maintenance
OD	Operational Day
OIRD	Operations Interface Requirements Document
OOL	Out-of-Limits
PA	Product Assurance
PC	Pre-Cooler
PCDU	Power Control & Distribution Unit
PCS	Power Control Subsystem
PFM	Proto Flight Model
PID	Parameter Identifier
PLFEU	Planck LFI Front End Unit (FEU)
PLM	Payload Module
PM	Project Manager
PPLM	Planck Payload Module
PR	Primary Reflector
PROM	Programmable Read Only Memory
PS	Project Scientist
PSO	Planck Science Office
PSVM	Planck Service Module
PV	Performance Verification
QA	Quality Assurance
QLA	Quick Look Analysis (software)
RAM	Random Access Memory
RD	Reference Document
RFW	Request for Waiver
ROM	Read Only Memory
RT	Real Time
RTA	Real-Time Analysis
S/C	Spacecraft
S/W	Software
SAA	Solar Aspect Angle
SC	SpaceCraft
SCC	Sorption Cooler Compressor
SCCE	Sorption Cooler Cold End
SCE	Sorption Cooler Electronics
SCOE	Special Check Out Equipment
SCOS	Spacecraft Control and Operations System
SCP	Sorption Cooler Pipes
SCS	Sorption Cooler Subsystem (Planck)
SFT	Short Functional Test
SID	Structure Identifier
SPACON	SPAcecraft CONtroller
SPR	Software Problem Report
SR	Secondary Reflector
SSMM	Solid State Mass Memory
SS	Stainless Steel
ST	Science Team
STMM	Simplified Thermal Model
SVM	SerVice Module
SVT	System Validation Test
TBC	To Be Confirmed
TBD	To Be Defined

TBS	To Be Specified
TBW	To Be Written
TC	TeleCommand
TCS	Thermal Control System
TID	Task Identifier
TM	Telemetry
TMM	Thermal Mathematical Model
TMP	Telemetry Processor
TMU	Thermo Mechanical Unit (Sorption cooler)
TOD	Time-Ordered Data
TOI	Time-Ordered Information
TQL	Telemetry Quick-Look
TV/TB	Thermal Vacuum/Thermal Balance (Test)
UM	User's Manual
URD	Users Requirements Document
UTC	Universal Time Coordinate(d)
VG	V-Groove radiator
WR	Warm Radiator
WU	Warm Units

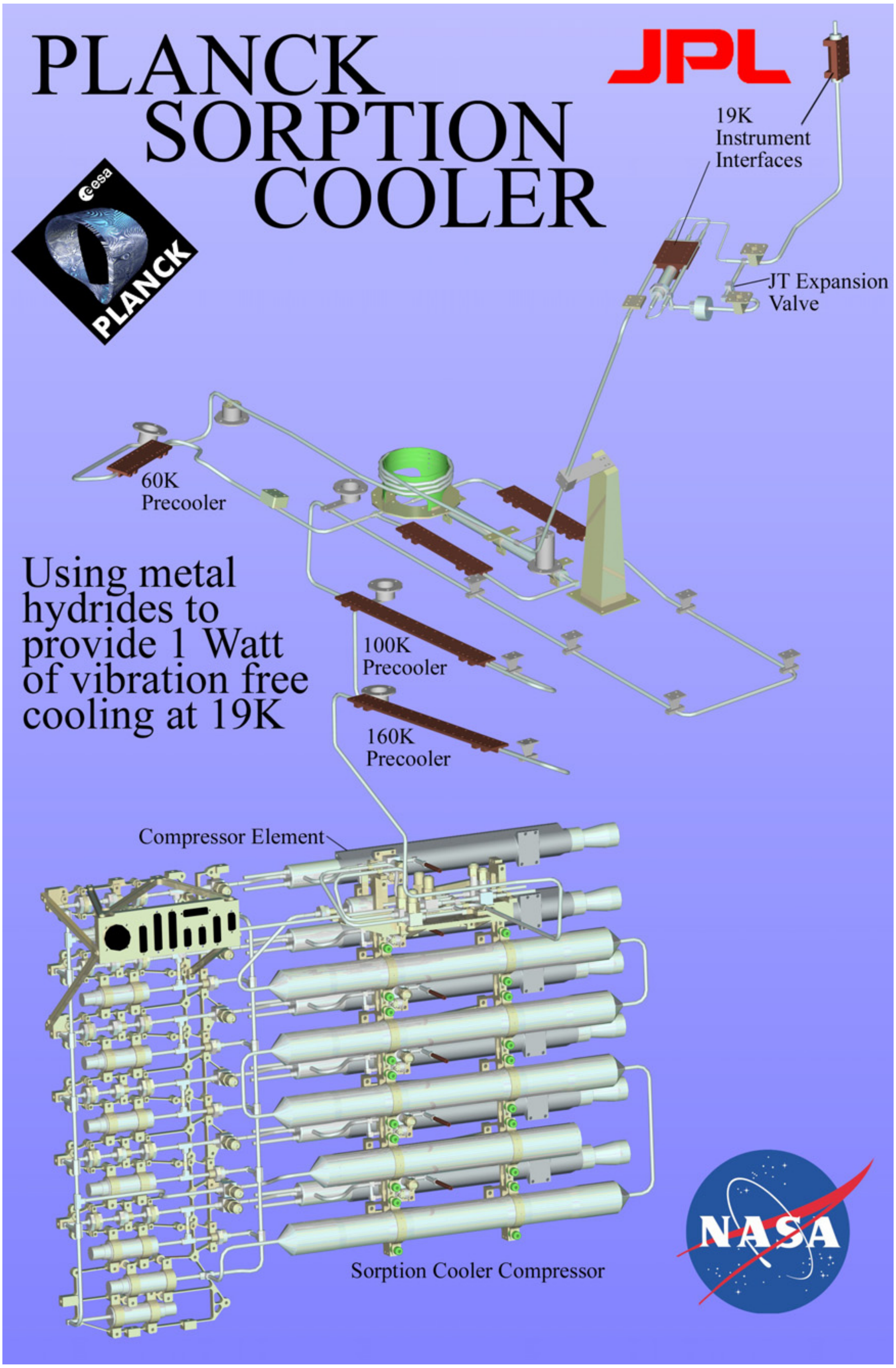
APPLICABLE & REFERENCED DOCUMENTS

Applicable Documents

Ref.	Doc. Ref. Nr.	Issue/ Rev	Document Title
AD-01	PT-IID-A-04624	4.0	FIRST/PLANCK INSTRUMENT INTERFACE DOCUMENT – PART A
AD-02	PT-LFI-04142	2.1	FIRST/PLANCK INSTRUMENT INTERFACE DOCUMENT – PART B
AD-03	PL-LFI-PST-ID-002	3.1	Planck Sorption Cooler ICD
AD-04	ES518265	B1	TMU Specification Document
AD-05	TS-PSCBC-100010-LPSC	8/2	Planck Sorption Cooler Electronics OBSW TC and TM Structures

Referenced Documents

Ref.	Doc. Reference Nr	Issue/Rev	Document Title
RD-01	PL-LFI-PST-UM-002	3.0	Planck Sorption Cooler User Manual
RD-02	PL-LFI-PST-PL-014	1.0	Planck Sorption Cooler System COP and CPV Test Plan
RD-03	MOC document	1.0	SCS Commissioning and CPV Definition
RD-04	PL-LFI-PST-RP-081	1.0	Planck SCS Bad Bed Detection Procedure Anomaly Report
RD-05	PL-LFI-PST-RP-082	1.0	Planck SCS Cold End Temperature Fluctuations Report


PLANCK
SORPTION
COOLER
JPL
19K
Instrument
Interfaces
JT Expansion
Valve
60K
Precooler
Using metal
hydrides to
provide 1 Watt
of vibration free
cooling at 19K
100K
Precooler
160K
Precooler
Compressor Element
Sorption Cooler Compressor
NASA
PLANCK
esa

1. Introduction

This document reports the SCS flight Commissioning Phase (COP) results. The unit activated for COP and CPV is FM2, officially considered the Nominal one (SCS-N) of the two delivered by JPL.

The SCS Flight Commissioning campaign spread over 2 weeks in June 2009.

This report covers all the results and issues related to the SCS activities only.

2. Commissioning Activities

The Sorption Cooler Commissioning Phase (COP) includes SCS-N activation and cooldown. The SCS COP is considered completed when the system autonomously enters Normal Mode and runs steadily in this operational mode. Since one of the main objective of this phase is to provide the instruments with a stable reference for their commissioning and calibration activities, in this report are described also the first steps of system calibration: Compressor and TSA tuning.

The Planck Sorption Cooler System nominal unit was activated on June 3rd 2009 by energizing the Sorption Cooler Electronics (SCE). On the following day, the system has been telecommanded into RUN - Conditioning Mode in order to start the active cooldown for the Planck Mission.

SCS COP sequence included three activites:

#	Activity Name	Commissioning Reference	Description
1	SCS Activation	P_COP/PVP_SCS_0001_01	SCS-N into RUN Mode (first system goes in Startup until the end of cooldown when it auto enters Nominal Mode. This ends COP)
2	SCS Compressor Tuning	P_PVP_SCS_0002_01	Adjust Compressor parameters
3	SCS TSA Tuning	P_PVP_SCS_0003_01 & 02	Adjust TSA Active Control parameters (in two steps)

SCS operational sequence during COP/CPV Phases is summarized in Figure 1

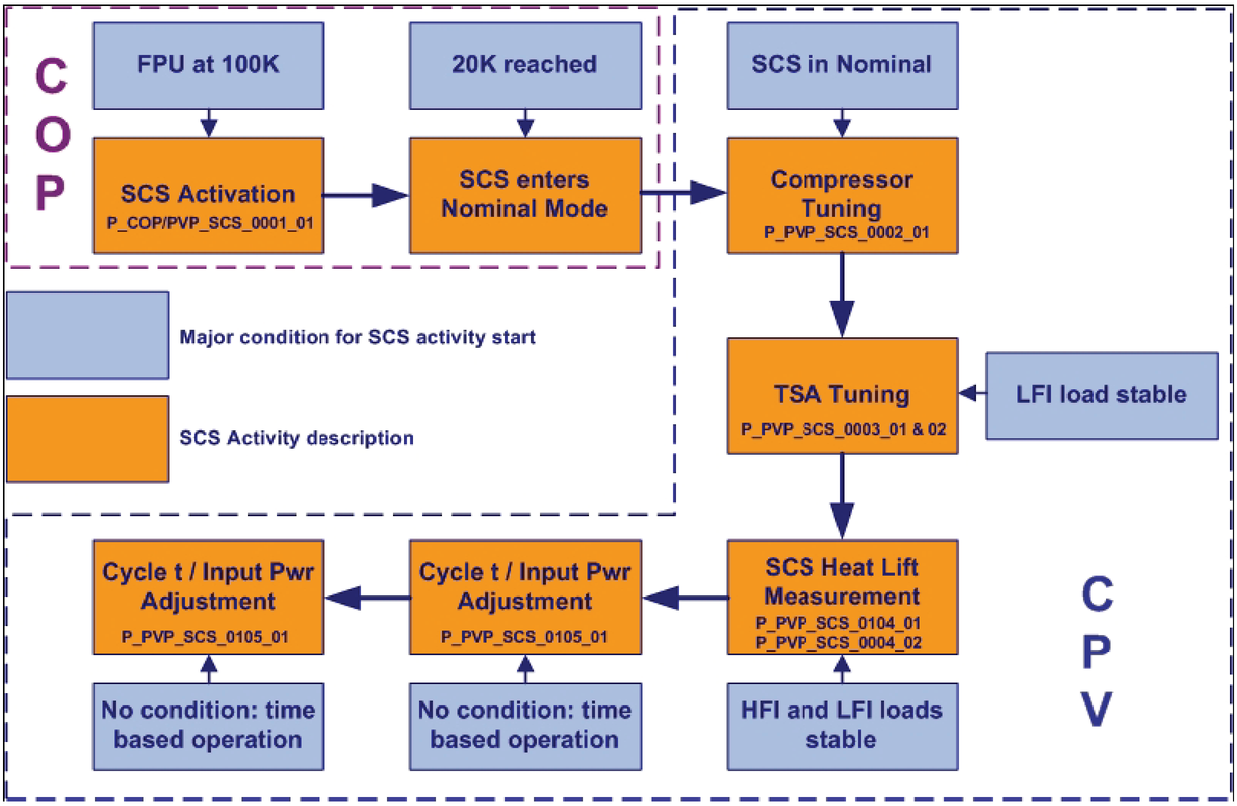


Figure 1. SCS COP/CPV phases sequence

2.1. Test Objectives

The main objectives of the Sorption Cooler Commissioning Phase are:

- Activate SCS and take it into stable Normal operations
- Execute cooldown of instruments interfaces from 100K to about 20K
- Provide a stable reference temperature for instruments commissioning and calibration

2.2. Test History

The SCS-N unit was activated on Wednesday June 3rd 2009 (DOY 154) and SCS COP was considered completed by Wednesday June 17th, for a total of 15 days.

3. SCS COP Test Matrix

All planned activities have been successfully executed.

Activity	Description	Commissioning Reference	Result
SCS Activation	SCS-N first into RUN - Conditioning and then autonomously in RUN - Normal	P_COP/PVP_SCS_0001_01	✓
SCS Compressor Tuning	Adjust Compressor parameters	P_PVP_SCS_0002_01	✓
SCS TSA Tuning	Adjust TSA Active Control	P_PVP_SCS_0003_01	✓
		P_PVP_SCS_0003_02	✓

4. COP Activities Results

4.1. SCS Activation – P_COP/PVP_SCS_0001_01

Objective of SCS activity P_COP/PVP_SCS_0001_01 was to start the SCS-N by commanding it into Run Mode and, finally, Normal Operations.

On June 3rd (DOY 154), the day before reaching the thermal condition for SCS start-up (LFI FPU < 100K), the SCE was switched On in READY Health Monitoring, in order to monitor the remaining part of PPLM cooldown. Objective of this preliminary step was to check the SCE basic functionality, monitor the system to assess the health status and to dump/check the onboard LUTs.
Once all these steps were performed the system was left in Health Monitoring, ready to be sent into RUN – Conditioning on the following DTCP, as soon as the temperature requirement was met.

One of the objective of these preliminary activities was to check the SCS synchronization after the problems that occurred in thermal vacuum conditions during cryogenic testing at CSL. A synchronization test is performed every day beginning with the flight activities and the average result has been always within a few lsb. This level of synchronisation accuracy is more than acceptable for SCS operations.

The Sorption Cooler Electronics behaviour is conforming to specifications and requirements, the measurement ranges and resolution are as expected. All functional modes entered up to now performed without issue.

The SCS operations cycle was started at 15:49 UTC of June 4th (DOY 155) by sending the system into RUN - Conditioning. The start-up sequence went exactly as expected and pressurization took about 70 min (see Figure 2). The pressure *(of what????)* was then steadily maintained in the range 32-34.5 bars during the whole cooldown process.

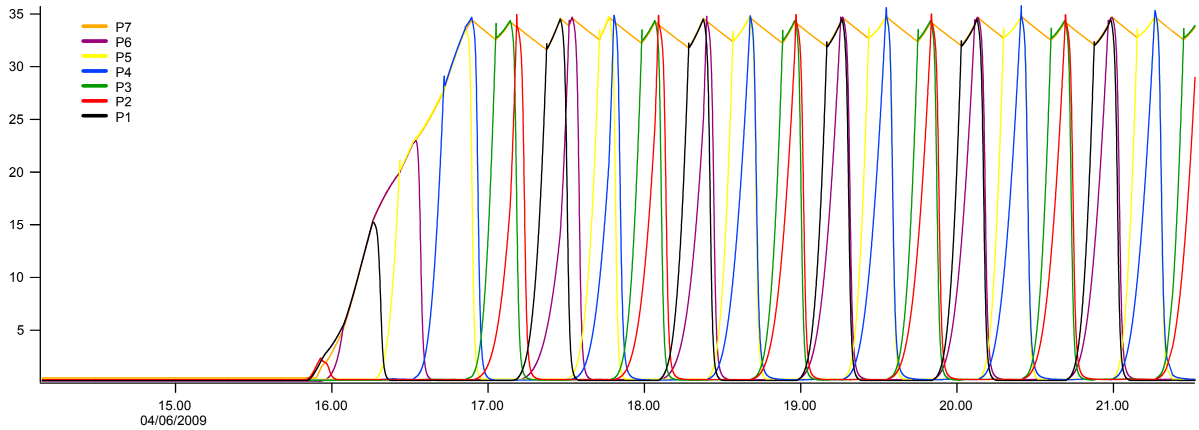


Figure 2. SCS pressurization

The startup and cooldown processes, shown in Figure 3, were performed as expected. Cooldown was within the predictions of the PPLM thermal model.

Liquid hydrogen was produced, and then 20K reached at LVHX1, 187 hours after the transition into RUN, and Normal Mode was entered about 9 hours after liquid production: event TM(5,1) for transition into Normal was generated @ 2009.163.19.39.57 (see Figure 4). In general, the cooldown went faster than TV ground testing: at CSL the same two milestones were reached in, respectively, 200 and 220 hours (Figure 5). This difference in cooldown time can be explained by the more efficient radiative passive cooling in flight and by the optimized operational strategy of cryochain heat-switch activation.

4.1.1. P_COP/PVP_SCS_0001_01 results and Verification Matrix

The Pass/Fail criteria for this activity were:

- No unexpected event Packets
- SCS shall enter RUN Mode
- SCS shall enter Nominal Operations

The results are summarized in the verification matrix below:

Phase #	**P_COP/PVP_SCS_0001_01**				
Test name:	SCS Activation				
Test objectives:	To start the SCS-N and take it into Run Mode and Nominal Operations.				
Verification matrix					
Check	**Passed?**			**Recovered?**	
	Yes	**No**	**Notes**	**Yes**	**No**
No unexpected events packets		(red)	Bad Bed detection procedure anomaly caused the cooler to go to READY Mode and stop cycling. Immediate analysis found the root cause and the cooler was re-started with minor impact on cooldown time. For details refer to RD-04.	✓	
SCS shall enter RUN Mode	✓		RUN Mode entered as expected	N/A	N/A
SCS shall enter Nominal Operations	✓		A very smooth transition into Nominal has been observed	N/A	N/A
SCS shall meet performance requirements	✓		Performance requirements met in Nominal Mode	N/A	N/A

During cooldown, a Bad Bed Detection Procedure anomaly caused the Sorption Cooler to go back to READY Mode and stop cycling. Immediate analysis found the root cause, and the cooler was re-started with minor impact on the cooldown time.
For details on this contingency refer to Par. 5.1 and RD-04.

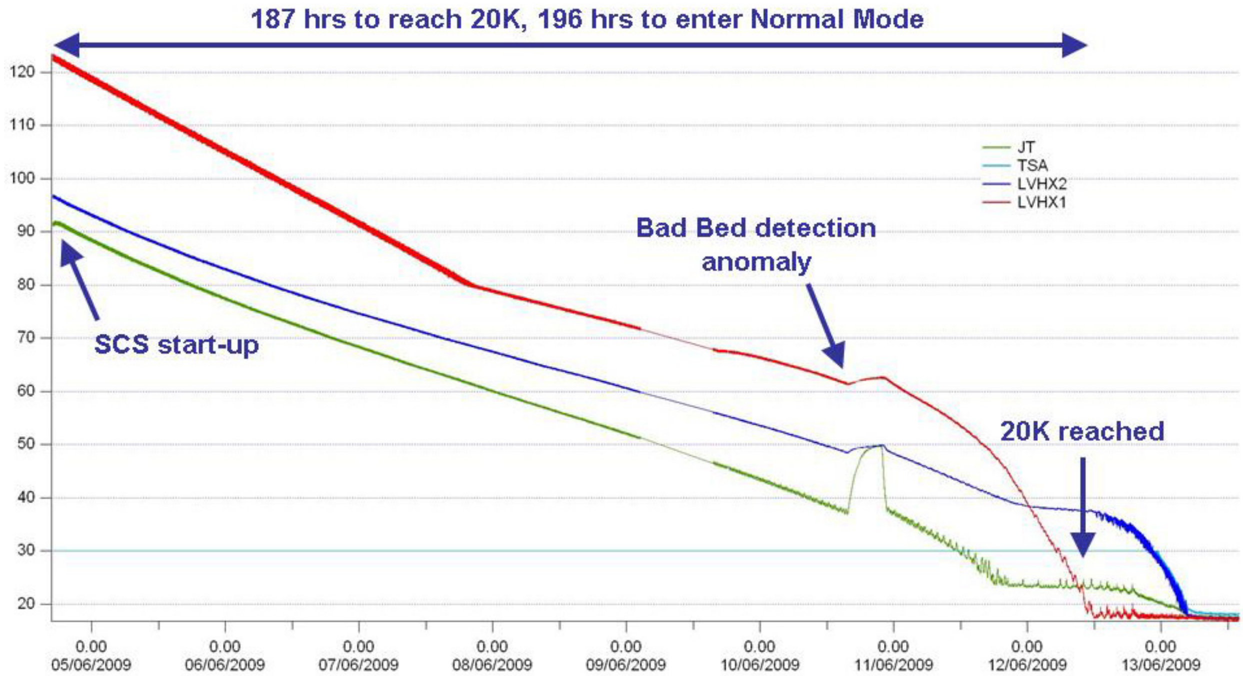


Figure 3. SCS flight cooldown

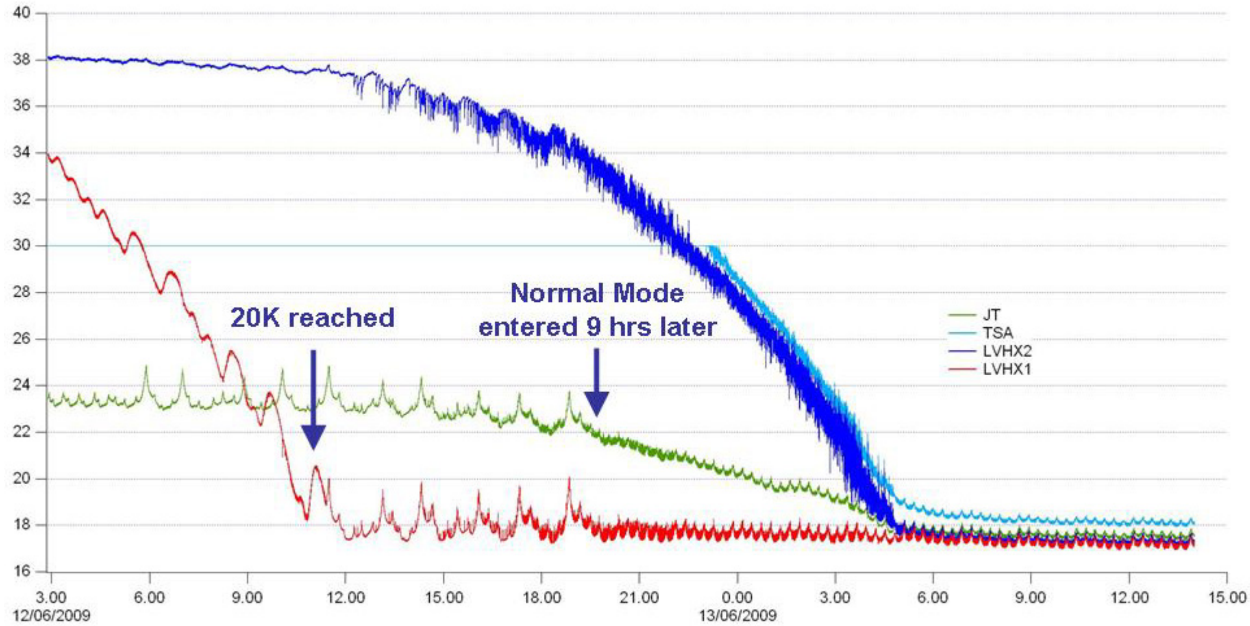


Figure 4. SCS Normal Mode transition

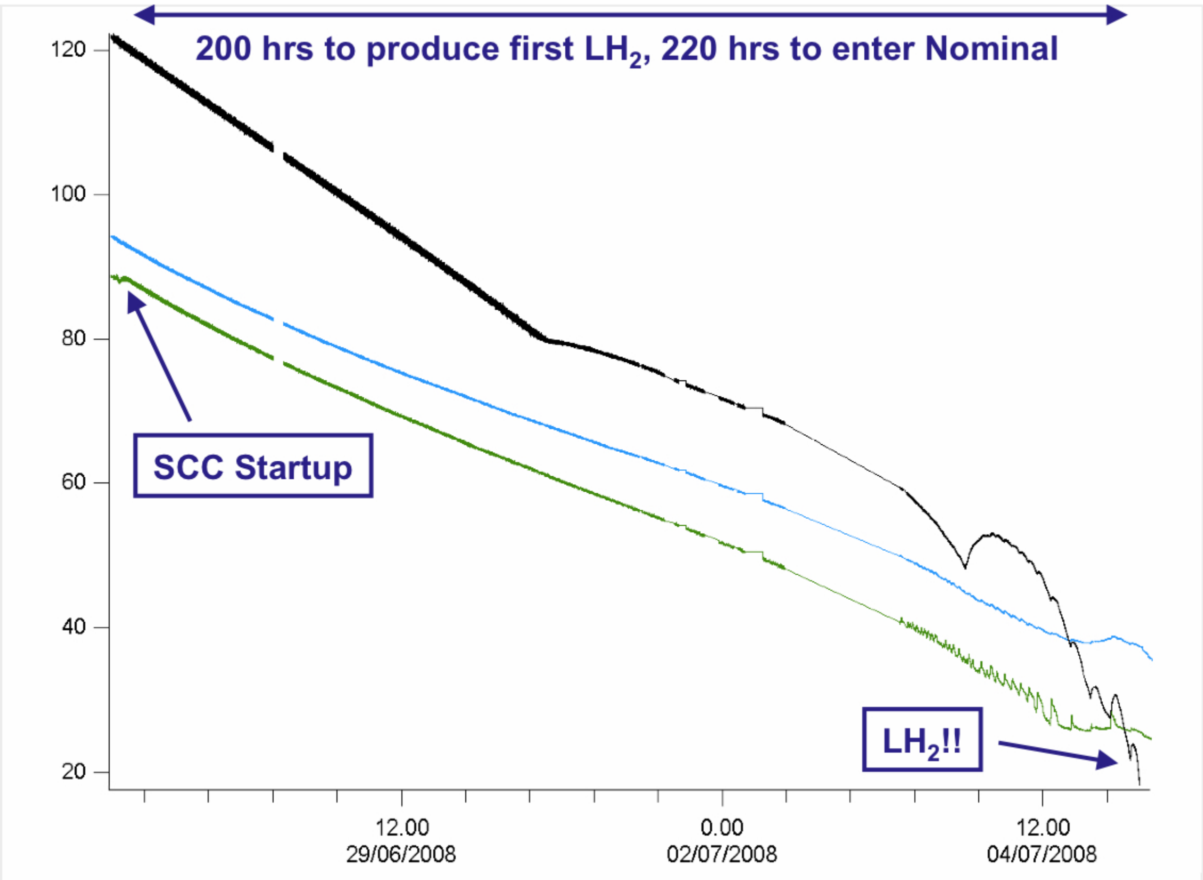


Figure 5. CSL PFM2 Cooldown of the SCS cold-end. Total time from SCS start-up to the production of liquid was 200 hours, 220 to enter Normal

4.2. SCS Compressor Tuning – P_PVP_SCS_0002_01

The objective of the second SCS activity in the timeline was the compressor operational parameters tuning in order to optimize cooler operations and performance for instrument commissioning. The main goal is to run the cooler in stable nominal conditions for a month during HFI and LFI calibration. This is a fundamental step for the whole COP/CPV phase, given that an out of balance SCS has a strong impact on the thermal status of other sub-systems and of the whole thermal status of the S/C.

4.2.1. P_PVP_SCS_0002_01 results and Verification Matrix

The Pass/Fail criteria for compressor tuning were:

- No unexpected event Packets
- SCS shall remain in Nominal Operations
- SCS shall meet performance requirements

The cooler parameters used for flight startup and cooldown were set before launch for lifetime optimization: Heatup Power = 100W, Desorption Power = 160W, LPSB Power = 1.35W and cycle time= 1050s.
Such settings were based on the prediction that in micro-gravity conditions the cold end fluctuations, due to two-phase flow phenomena, would reduce allowing longer cycle times and lower powers. With the higher than expected peak-to-peak oscillations observed at the cold end once in Normal Mode, it was decided for this first tuning step to try to reduce the overall peak-to-peak by returning to values closer to ground TV test settings. Decreasing the cycle time (and consequently changing the input power) allowed a reduction of the swing of the hydrides plateau. This, together with a lower LPSB working point, finally reduced the oscillations.
The two primary interface temperatures, of V-Groove3 and the Warm Radiator, are colder in flight than at CSL: 45.8K and 267 K, respectively, versus 47K and 270K. The new LUT values had to be calculated to cope with changed boundary conditions.
Table 1 summarizes the final cooler parameters for this first tuning activity executed during DTCP of June 14th DOY 165.

Case	Heatup power (W)	Desorption power (W)	LPSB power (W)	Cycle Time (s)
Flight	109	160	1.30	940
CSL Test	112	160	1.27	940

Table 1. Flight vs CSL Compressor Tuning settings

With respect to CSL settings, the heatup power was slightly reduced in order to optimize the timing with the desorption phase while the LPSB was increased to cope with the lower radiator temperature.

The results of the SCS Compressor tuning Activity can be summarized in the verification matrix:

Phase #	P_PVP_SCS_0002_01				
Test name:	SCS Compressor tuning				
Test objectives:	To adjust the SCS operational parameters for nominal cooler performance in order to ensure optimal conditions for instruments commissioning and calibration				
Verification matrix					
Check	Passed?			Recovered?	
	Yes	No	Notes	Yes	No
No unexpected event Packets	✓			N/A	N/A
SCS shall remain in Nominal Operations	✓		Once entered in Nominal Model, SCS quickly reached a stable working point and maintained itself in a steady state even in the occurrance of external conditions or load variations. The Cold End shows robustness against external perturbation by automatically adjusting cold end heat balance.	N/A	N/A
SCS shall meet performance requirements	✓		Cold End T's, Input Power, Cooling Power requirements are fully met	N/A	N/A
LVHX1 T fluctuations < 450 mK p-to-p			LVHX1 ΔT peak-to-peak have been osberved around 620mK 3σ rms variation are on the order of 320mK		AR Opened

Higher than expected temperature fluctuations on LVHX1 (interface to HFI) were observed at the end of the tuning (see Par. 5.2). An AR has been opened and the investigation is in progress.

4.3. SCS TSA Tuning – P_PVP_SCS_0003_01 and _02

Objective of this tuning activity is to adjust the TSA active control parameters relative to all other parameters to optimize the cold end absolute temperature and fluctuations of LVHX2 (interface to LFI). In this way the temperature oscillations at the LFI interface will be maintained at an acceptable level.

This activity was intended to be split over two consecutive DTCPs: in the first DTCP the PID parameters would be adjusted and the required temperature stability achieved; the second DTCP was used to check if stability had been maintained and, if needed, to perform extra adjustment.

P_PVP_SCS_0003_01 was performed on June 15th DOY 166: at the end of the DTCP stabilization was achieved. Due to Commissioning timeline and mission operational constraints, P_PVP_SCS_0003_02 was deferred to June 17th DOY168. TSA stability was then monitored for 2 consecutive DTCPs without showing any degradation. Level of fluctuations at the LFI interface was considered acceptable for instrument calibration so no further tuning was performed.

LFI tuning activities are directly related to cooldown timing. In order to minimize the time needed to reach an acceptable level of stability, the CSL PID tuning parameters were used to start the tuning. A few steps were performed to optimize the combination between PID gains and control set-point. Final PID parameters values and stability results are reported in the following table:

Case	P	I	D	Set-point	pp ΔT (mK)	3σ ΔT (K)
Flight	500	15	0	18.5	140	70
CSL Test	500	15	0	18.7	120	60

Table 2

During TSA tuning, the Open Loop algorithm option was also activated to achieve better stabilization.

The Pass/Fail criteria for TSA tuning are:

- No unexpected event Packets
- SCS shall remain in Nominal Operations
- SCS shall meet performance requirements
- Peak-to-peak T fluctuations at the TSA stage shall be below 100 mK, while LVHX1 ΔT shall remain below 450 mK

Results are reported in the following verification matrix:

Phase #	**P_PVP_SCS_0003_01 and _02**				
Test name:	SCS TSA tuning				
Test objectives:	To adjust the TSA active control parameters in order to ensure stable T reference for LFI commissioning and calibration				
Verification matrix					
Check	**Passed?**			**Recovered?**	
	Yes	**No**	**Notes**	**Yes**	**No**
No unexpected event Packets	✓			N/A	N/A
SCS shall remain in Nominal Operations	✓		Over the days SCS showed a very steady behavior even in presence of boundary conditiongs (e.g instruments load) changes.	N/A	N/A
SCS shall meet performance requirements	✓		Cold End T's, Input Power, Cooling Power requirements are fully met	N/A	N/A
TSA T fluctuations < 100 mK p-to-p			TSA ΔT peak-to-peak have been osberved around 140mK 3σ rs variation are on the order of 70mK		**AR Opened**

As shown in Table 2, at the end of P_PVP_SCS_0003_01 and 02 stability was very close to CSL level. 3σ variations, a more reliable evaluation tool of average fluctuations than the pp delta, show that the two cases (flight and ground) are similar. In both cases, the pp temperature oscillations were not meeting requirements. For this reason, as it was after CSL TV test, an AR was opened and investigation is in progress (see Par. 5.2 and RD-05).

5. Anomalies

5.1. Bad Bed Detection Anomaly Report

At the opening of the DTCP of day 161, June 10th, at 15:10 UTC, it was observed that compressor elements 1 and 4 had been removed from the compressor cycling process by the Bad Bed procedure of the SCS software. Subsequently, at 15:37 UTC, compressor element (CE) 6 was removed by this process, and, per the Bad Bed procedure, the SCS compressor was turned off and the system entered health monitoring mode.
After analysis of the problem, the root cause was found: autonomous bed performance check limits were too tight for cooler operational parameters in flight and actual flight boundaries condition. To solve the issue, changes to LUT were applied and the cooler was restarted 5 hours after the anomaly, with minor impact on the PPLM cooldown time as demonstrated also by the faster than CSL cooldown time.

An AR was opened and closed on this issue (ID = P_SC-18).

For a detailed description of the Bad Bed Detection procedure Anomaly refer to RD-04.

5.2. Cold End Fluctuations

Flight level of Cold End temperature fluctuations is 10-15% higher than CSL test, but still comparable. In fact, the difference shown in the pp values is generated by few isolated peaks with minor, often negligible, impact on the thermal behaviour of the instruments side of the interfaces. 3σ variations provide a more reliable evaluation tool of average fluctuations than the pp delta. They show that the two cases (flight and ground) are very similar even if, in both cases, the pp temperature oscillations were not meeting requirements. Results are reported in the following table:

Case	I / F	Average T (K)	pp ΔT (mK)	3σ ΔT (K)
Flight	LVHX1	16.9	620	320
	TSA	18.5	140	70
CSL Test	LVHX1	17.0	560	320
	TSA	18.7	120	60

The main differences with CSL results are:

- an extra 60 mK pp on the compressor modulation
- a different dynamical behaviour of the two phase flow in micro-g

The first can be recovered with the further steps of SCS compressor tuning (see RD-05).

The second is an intrinsic behaviour of the cold end that can be only mitigated by controlling the system excess liquid production.

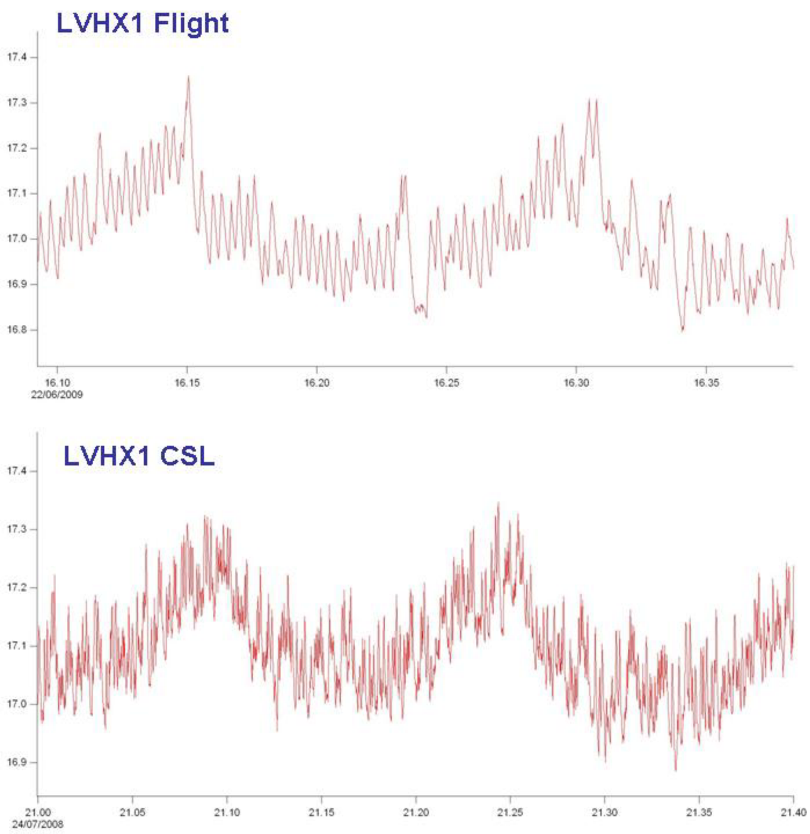


Figure 6. Flight vs CSL cold end T fluctuations

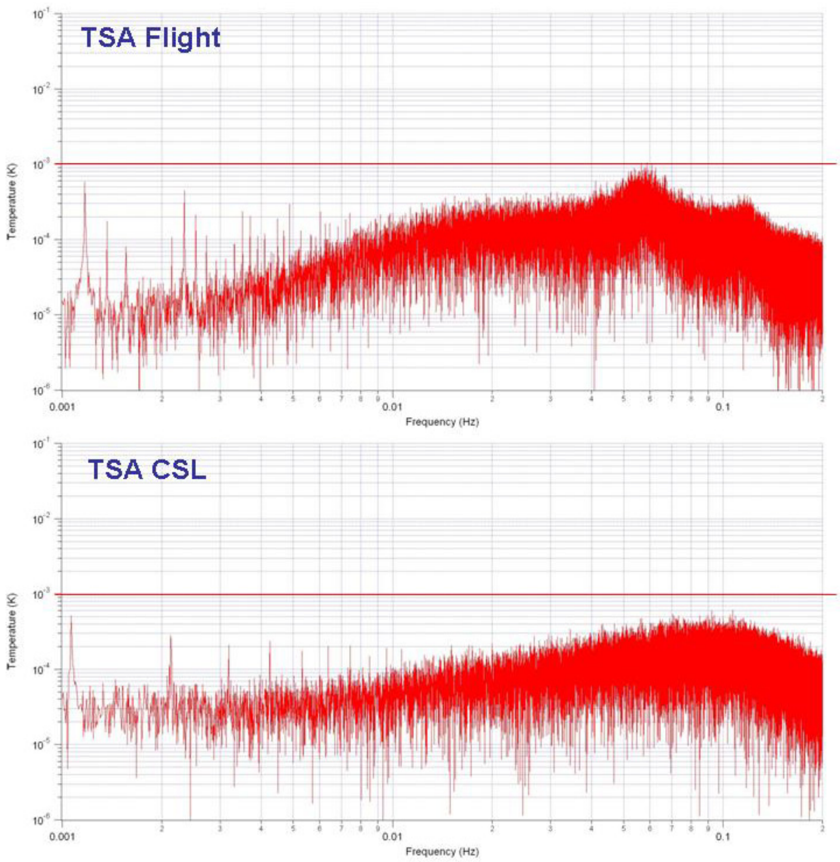


Figure 7. Flight vs CSL TSA frequency spectrum

Comparing flight vs CSL cold end fluctuations in Figure 6, clearly shows not only how the low and high frequency pp variations are similar but also how the flight high frequency component (due to plug flow in micro-g) is much more regular. Typical duration of each spike in flight is about 15-20s and the peaks period is very regular around 20s. On ground, cold end oscillations showed more irregular contributions from different frequencies.
This different behaviour explains the sharp 0.05Hz peak shown in the flight TSA spectrum (Figure 7) that was not present in the CSL test data. At the same time, the lower (<0.01Hz) and higher (>0.07Hz) sides of the frequency spectrum in flight are lower than on the ground.

For a detailed description of the Cold End temperature fluctuations Anomaly refer to RD-05.

6. Lifetime

No sign of degradation has been observed after 2 weeks of operations in Normal Mode. Main thermal interfaces (Warm Radiator and VG3) are slightly lower than at CSL but, at present, lifetime estimation remain unchanged with respect to CSL pre-flight prediction.

After one month of SCS-N operation in flight, based on present loads and interface temperatures, the lifetime of the two sorption coolers are estimated to be 14.5 months for the Nominal unit (FM2) and 13.5 months for the Redundant (FM1). The uncertainty in these numbers is +/- 0.5 months.

7. Summary

SCS COP reached the main objectives:

- SCS has been activated and is running stably in Normal Operations
- Instruments interfaces have been cooled down from 100K to about 17K with temperature stability levels acceptable for commissioning and calibration activities

All SCS activities were performed as expected in terms of operating procedures and test results: commissioning phase of the cooler can be considered successfully concluded.

SCS activities will now proceed in CPV with next tuning steps:

- P_PVP_SCS_0004_01, Heatlift measurement
- P_PVP_SCS_0005_01, Cycle Time and Power adjustment (several iterations)