SPIRE Science Verification Review

RAL

September 26, 27 2006

Thermal Performance

Document Number: SPIRE-RAL-REP-002557

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Date
15/09/06

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Changes

Issue	Date	Section	Description
0.1	13/06/06	-	First Draft.
1.0	13/06/06	-	First Issue.
2.0	15/09/06	All	Document updated to include results from PFM3 test campaign and thermal model correlation.
		1.2	New applicable documents added.
		2.2	Table updated with PFM4 as necessary
		3.1.1	Table updated with thermal tests performed during PFM3 campaign
		3.1.1.1 3.1.1.2	Wording of sections updated (highlighted in blue in document)
		3.1.1.4	New section summarising the outcome of PFM3 test campaign
		3.1.2	Updated with the list of thermal tests planned for the PFM4 test campaign.
		3.2 / 3.3	Both sections merged into section 3.2 to make document easier to follow. Updated with most recent data.
		4 / 5	Updated with most recent data.
		6	New section

Acronyms

Acronym	Definition
AD	Applicable Document
BDA	Bolometer Detector Arrays
BSM	Beam Steering Mechanism
CBB	Cold Black Body
CQM	Cryogenic Qualification Model
DRCU	Digital Readout Control Unit
DTMM	Detailed Thermal Mathematical Model
EGSE	Electronic Ground Support Equipment
FM	Flight Model
FPU	Focal Plane Unit
FS	Flight Spare
HOB	Herschel Optical Bench
HeI	Helium I
HeII	Helium II
I/F	Interface
IIDB	Instrument Interface Document Part B
IRD	Instrument Requirement Document
JFET	Junction Field Effect Transistor
L0	Level-0
L1	Level-1
L2	Level-2
L3	Level-3
LN2	Liquid Nitrogen
MGSE	Mechanical Ground Support Equipment
PFM	Proto Flight Model
RD	Reference Document
SMEC	Spectrometer Mechanism
SOB	SPIRE Optical Bench
SPIRE	Spectral and Photometric Imaging Receiver
TBT	Thermal Balance Test
DTMM	Detailed Thermal Mathematical Model

Contents

List of Tables

1. Introduction and scope

1.1 Scope

The scope of this document is to report about:

- Thermal test results obtained during the CQM, FM and EQM test campaigns that are relevant to the in-flight instrument scientific performances,
- Any remaining/additional thermal tests required to complete the validation of the instrument thermal performances,
- Provide inputs for the system-level verification requirements.

1.2 Applicable Documents

AD	Title	Document Number
AD1	SPIRE CQM Thermal Balance Test Specification	SPIRE-RAL-DOC-002077 Draft 4.5
AD2	SPIRE CQM Thermal Balance Test Report	SPIRE-RAL-REP-002078 Issue 1
AD3	SPIRE PFM2 Thermal Balance Test Specification	SPIRE-RAL-DOC-002435 Issue 1
AD4	SPIRE PFM2 Thermal Balance Test Report	SPIRE-RAL-REP-002534 Issue 1
AD5	SPIRE Thermal Balance Test Sequence and Requirements For EQM Testing	SPIRE-RAL-NOT-002319 Issue 1
AD6	Subsystem Verification Matrix - SPIRE Thermal Hardware	Working Version 3.2
AD7	SPIRE 300-mK and Level-0 straps Subsystems Thermal Performances Assessment	SPIRE-RAL-NOTE-002129 Issue 1
AD8	SPIRE CQM2 Thermal Test Results Memo	SPIRE-RAL-MEM-002533 Issue 1
AD9	Analysis of SPIRE Thermal Performances with Hybrid FPU Supports	SPIRE-RAL-NOT-002551 Issue 1
AD10	SPIRE PFM3 Thermal Balance Test Specification	SPIRE-RAL-MEM-002563 Issue 1
AD11	Flight L0 Thermal Straps Test Report	Cardiff 15/11/05
AD12	Herschel Thermal Model Issue Email Object: RE: PFM Cryostat - SPIRE L1 Flexibles Thermal Conductance (TB Test in LSS)	05/12/05 Email from A. Hauser
AD13	Use of BSM during spectrometer mode Email Object: RE - PFM Power II	23/02/04 Email from D. Griffin

AD14	BSM Power Dissipation Emails Object: PFM Power and PFM Powers II	10/02/04 Email from B. Swinyard
AD15	SMEC Power Dissipation Update Emails Object: SMEC Consumption	07/07/05 Email from B. Swinyard
AD16	SPIRE PFM2 Thermal Performance Flight Predictions	SPIRE-RAL-NOT-002588 Issue 1
AD17	SPIRE PFM3 Thermal Balance Test Report	SPIRE-RAL-REP-002684 Draft B
AD18	SPIRE Cooler Performance Degradation	SPIRE-RAL-MEM-002693 Issue 0.1
AD19	SPIRE Flight Thermal Model Correlation Report	SPIRE-RAL-REP-002723 Draft A
AD20	SPIRE System Level Test Plan – Inputs to Thermal Section System Level Thermal Test Plan.doc	Email from A. Goizel 01/09/06
AD21	Subsystem Verification Matrix - SPIRE Thermal Hardware	Working Version 4.0
AD22	Herschel TB/TV Test Evaluation Report Evaluation of Instrument Thermal Interface Test Results	HP-2-ASED-RP-0180 Issue 1
AD23	Inputs to PFM4 Thermal Test Specification	SPIRE-RAL-MEM-002722 Draft B

Table 1-1 – Applicable Documents

1.3 Reference Documents

RD	Title	Document Number
RD1	Instrument Interface Document Part A	SCI-PT-IIDA-04624 3.3
RD2	Instrument Interface Document Part B - SPIRE Instrument	SCI-PT-IIDB/SPIRE-02124 Issue 3.2
RD3	SPIRE Instrument Requirement Document	SPIRE-RAL-PRJ-000034 Issue 1.3
RD4	SPIRE Cryogenic Thermal Design Requirements	SPIRE-RAL-PRJ-002075 Issue 1

Table 1-2 - Reference Documents

2. List of requirements that the test programme was designed to evaluate

2.1 Overview

In order to meet its science goals, the SPIRE instrument has been designed to meet the following high-level requirements:

- Cooler hold time ≥ 46-hr,
- Absolute detector assemblies' temperature ≤ 310mK.

Both requirements shall be met with SPIRE operating in the thermal environment described in Table 2-1.

In-Orbit Thermal Requirements [1]			
SPIRE FPU Thermal IF	Maximum I/F Temperature at Max Heat Load		Cooler State
	Requirements	Goals	
Level 0 – Detector Box	2 K @ 4 mW	1.71K @ 1 mW	Operating
Level 0 – Cooler Pump	2 K @ 2 mW	2 K @ 2 mW	Operating
	10 K @ 500 mW peak	10 K @ 500 mW	Recycling
Level 0 – Cooler Evaporator	1.85 K @ 15 mW	1.75 K @ 15 mW	Recycling
Level 1	5.5 K @ 15 mW	3.7 K @ 13 mW	Operating
Level 2	12 K @ no load	8 K @ no load	Operating
Level 3 – Photometer	15 K @ 50 mW	15 K @ 50 mW	Operating
Level 3 – Spectrometer	15 K @ 25 mW	15 K @ 25 mW	Operating
Instrument Shield	16 K	16 K	Operating

Table 2-1 – SPIRE High-Level Thermal Requirements

Subsystems and instrument level requirements have been derived from these high-level requirements and are summarised in the Instrument Requirement Document [RD3] and the SPIRE Cryogenic Thermal Design Requirements [RD4]. A SPIRE Thermal Hardware Verification Matrix [AD21] has been compiled to keep track of their verification method and status depending of the instrument model being tested. Table 2-2 in the following section provides a summary of the applicable instrument level thermal requirements. Please note that a definition of the acronyms used in the "Verification Method" and "Verification Model" columns is given in Table 2-3 in the following pages.

[1] *Assuming a ^{2}He tank temperature of 1.7 K.*

2.2 SPIRE Instrument Thermal Requirements

Requirement Name	Description	Requirement	Upper Link	Verfication Method	Verification Model
IRD-BSMP-R11	BSM Thermal Isolation	The BSM structure or mirror shall rise by no more than 1K from the nominal temperature of the surrounding after an hour of operation in any mode	IRD-OPTP-R08 IRD-OPTS-R09	D, A, ILTT, ILOP	PFM2, PFM3, PFM4
IRD-BSMP-R12	BSM Cold Power Dissipation	The dissipation should be within specification given in RD15 - 3mW maximum mean power dissipation during 46-hr operation	IIDB-Sect 5.9.1	D, A, ILTT, ILPT, ILOP	SS, PFM3, PFM4
IRD-CALP-R10	PCAL Thermal Isolation	The thermal conductance between the photometer calibrator body and the SOB shall be >2mW/K	Created	D, A, ILTT	PFM2, PFM3, PFM4
IRD-CALP-R12	PCAL Cold Power Dissipation	Shall be within the specification given in RD15 - 0.033 mW maximum mean power dissipation during 46-hr operation	IIDB-Sect 5.9.1	D, A, ILTT, ILOP	SS, PFM2, PFM3, PFM4
IRD-CALS-R09	SCAL Cold Power Dissipation	Shall be within the specification given in RD15 - 2mW maximum mean power dissipation during 46-hr operation	IIDB-Sect 5.9.1	D, A, ILTT, ILOP	SS, PFM3, PFM4
IRD-CALS-R12	SCAL Thermal Isolation	The SCAL enclosure shall provide an attachment point for a thermal strap to avoid the SCAL to warm up its environment by more than 1K	Created	D, A, ILTT	SS, PFM3, PFM4
IRD-CALS-R15	SCAL Thermometry	Thermometers shall be provided on the spectrometer calibrator as specified in section 3.5.12	Created	D, A, ILTT	PFM2, PFM4
IRD-CALS-R16	SCAL Time Response	Warmup Time: Stable nominal operating temperature to be reached in less than 30 min(reqt) 15 min (goal). Cooldown Time from nominal operating temperature to <10K: 3hr (reqt) 30 min (goal)	Created	D, A, ILTT, ILPT, ILOP	SS, PFM3, PFM4
IRD-COOL-R01	Temperature at the detectors	The 3He cooler, in conjunction with the associated 300 mK architecture, shall maintain all bolometer detector assemblies at less than 310 mK – goal 300 mK	IRD-PHOT-R04 IRD-PHOT-R05 IRD-SPEC-R06 IRD-SPEC-R07	D, A, ILTT, ILPT	CQM2, PFM2, PFM3, PFM4
IRD-COOL-R02	Operating temperature control	Desirable to vary the temperature of the detectors up to 320mK and below 300mK if permitted by thermal busbar.	Created	D, A, ILTT, ILPT, ILOP	PFM3, PFM4
IRD-COOL-R03	Temperature drop across thermal link between detectors and evaporator cold tip	Maximum of 20mK (Goal = 10mK)	IRD-COOL-R01	D, A, ILTT	CQM2, PFM2, PFM3, PFM4
IRD-COOL-R04	Temperature drift	Evaporator cold tip should drift by no more than 0.1mK/h under active control	IRD-PHOT-R05	D, A, ILTT	PFM3, PFM4

Requirement Name	Description	Requirement	Upper Link	Verfication Method	Verification Model
IRD-COOL-R05	Temperature fluctuations at the evaporator cold tip	10uK.Hz-1/2 in a 0.1-10 Hz band	IRD-PHOT-R04 IRD-PHOT-R05 IRD-SPEC-R06 IRD-SPEC-R07	D, A, ILTT, ILPT, ILOP	SS, PFM2, PFM3, PFM4
IRD-COOL-R07	Heat lift at evaporator cold tip	Minimum of 10uW at 290mK	Created	D, A, ILTT	SS
IRD-COOL-R08	Cooler Hold time	Minimum of 46 hrs	IIDA-Sect 5.13.2.5	D, A, ILTT	CQM2, PFM2, PFM3, PFM4, EQM
IRD-COOL-R09	Cooler Recycle time	Maximum of 2 hours	IIDA-Sect 5.13.2.5	D, A, ILTT	CQM2, PFM2, PFM3, PFM4, EQM
IRD-COOL-R11	Thermal Interface with Herschel cryostat	Cooler L0 Strap conductance Requirement of 150mW/K at 1.7K	Created	D, A	SS
IRD-COOL-R12	Parasitic thermal load onto He bath during cold operation	Pump L0 load in operation 2mW maximum	IIDB-Sect 5.7.1.3	D, A, ILTT	PFM2, PFM3, PFM4
IRD-COOL-R13	Time averaged thermal load onto He bath for 48 hour cycle	Total Energy 860J	IIDB-Sect 5.7.1.3	D, A, ILTT	SS
IRD-COOL-R18	Cooler Thermometers	Thermometers shall be provided on the cooler as necessary to monitor its behaviour and operation (see section 3.5.12). Absolute temperature measurement on evaporator cold tip shall be 1% (<3mK) with a resolution of 1mK.	Created	D, A, ILTT	PFM2, PFM4
IRD-DETP-R13	300 mK thermal load	The thermal dissipation and parasitic load at 300mK shall be within the specification given in RD15	IRD-COOL-R08	D, A, ILTT, ILPT	CQM2, PFM2, PFM3, PFM4
IRD-DETS-R14	300 mK thermal load	The thermal dissipation and parasitic load at 300mK shall be within the specification given in RD15	IRD-COOL-R08	D, A, ILTT, ILPT	CQM2, PFM2, PFM3, PFM4
IRD-FTB-R05	JFET Cold Power Dissipation	The dissipation of the JFET amplifiers shall be heat sunk to the L3 cryostat stage and shall be within the specification given in RD15 - 42mW and 14mW maximum mean power dissipation during 46-hr operation for PJFET and SJFET respectively	IIDB-Sect 5.9.1	D, A, ILTT, ILPT, ILOP	SS, PFM2, PFM3, PFM4

Requirement Name	Description	Requirement	Upper Link	Verfication Method	Verification Model
IRD-FTB-R11	JFET Thermal Isolation	The JFET structure shall be thermally isolated from the Herschel optical bench with specification given in RD15 - Less than 0.005W/K (goal 0.002W/K).	IIDA-Sect 5.7.1.2	A,D,ILTT	CQM2
IRD-FTB-R12	L3 Thermal IF	The JFET structure shall be thermally connected to L3 via a strap with interface specification given in RD15 - 0.138W/K at 15K	IIDB-Sect 5.7.1.3	D, A, ILTT, ILPT	PFM2, PFM3, PFM4
IRD-SMEC-R11	SMEC Cold Power Dissipation	The dissipation should be within specification given in RD15 - 3.2mW maximum mean power dissipation during 46-hr operation	IIDB-Sect 5.9.1	D, A, ILTT, ILPT, ILOP	SS, PFM4
IRD-SMEC-R13	SMEC Temperature Sensor	The SMEC shall provide thermometers as detailed in section 3.5.12.	Created	D, A, ILTT	SS, PFM4
IRD-STRC-R05	Surface Finish of the Common Structure Cover	The inside and outside of the box shall have a finish with a low emissivity. At least e = 0.2. Some parts of the structure walls may be blackened as part of the straylight control.	RD15	D, A, I , ILTT	PFM2, PFM3, PFM4, EQM
IRD-STRC-R07	Thermometry	The structure subsystem shall provide thermistors and associated wiring to allow the temperature of critical parts to be monitored during in-flight operations – see section 3.5.12	Created	D, A, ILTT	PFM2, PFM4
IRD-STRC-R14	FPU Thermal Isolation	The conductance from the level 2 to level 1 stage shall be within the specification given in RD15.	Created	D, A, ILTT	PFM2, PFM3, PFM4
IRD-STRC-R15	SOB Temperature	The SPIRE Optical Bench shall be connected to the L1 stage with a thermal conductance meeting the requirements in RD15 - 1.5W/K at 5.5K	Created	D, A, ILTT	PFM3, PFM4
IRD-STRP-R04	Surface Finish	The outside of the box shall have a finish with a low emissivity. At least e = 0.2. The inside of the box shall have a low reflectivity finish on all non-optical surfaces.	RD15	D, A, I	CQM2, PFM2, PFM3, PFM4
IRD-STRP-R09	L0 Phot Thermal Isolation	The conductance along the photometer detector box mechanical support from L1 to L0 shall be within the specification set in RD15	Created	D, A, ILTT	PFM2, PFM3, PFM4
IRD-STRP-R10	Photometer Box Temperature	The photometer box shall be connected to the spectrometer box with a strap meeting the conductance requirements in RD15 - 0.05W/K at 1.7K	Created	D, A, ILTT	CQM2, PFM2, PFM3, PFM4
IRD-STRS-R04	Surface Finish	The outside of the box shall have a finish with a low emissivity. At least e = 0.2. The inside of the box shall have a low reflectivity finish on all non-optical surfaces.	RD15	D, A, I	CQM2, PFM2, PFM3, PFM4
IRD-STRS-R08	L0 Spectr Thermal Isolation	The conductance along the spectrometer detector box mechanical support from L1 to L0 shall be within the specification set in RD15	Created	D, A, ILTT	PFM2, PFM3, PFM4
IRD-STRS-R09	Spectrometer Box Temperature	The spectrometer box shall be connected to the cryostat L0 stage with a strap meeting the conductance requirements in RD15 - 0.15 W/K at 1.7K	Created	D, A, ILTT	SS

Table 2-2 – SPIRE Instrument Thermal Requirements Summary [AD21]

Note: RD15 is the above table refers to the "SPIRE Cryogenic Thermal Design Requirements" document [RD4] in this document.

Verification Method	D	Design
	A	Analysis
	I	Inspection
	ILTT	Instrument Level Thermal Tests
	ILPT	Instrument Level Performance Tests
	ILCFT	Instrument Level Cold Functional Test
	ILOT	Instrument Level Operations Tests
Verification Model	SS	Subsystem Level
	SC	Spacecraft Level
	CQM1	First CQM Test Campaign
	CQM2	Second CQM Test Campaign
	PFM2	Second PFM Test Campaign
	PFM3	Third PFM Test Campaign
	PFM4	Fourth PFM Test Campaign
	EQM	EQM Test Campaign

Table 2-3 – Acronyms used for Verification Matrix

3. Test results and conclusions

3.1 List of tests carried out and tests still to be done

The following sections summarise the tests that have been carried out to date at instrument level, including a brief summary of the tests outcomes and conclusions for each test campaign. A final section provides an overview of the test remaining to be done in order to complete the verification of the instrument thermal performance.

3.1.1 List of tests carried out during the CQM/PFM/EQM Test Campaigns

Test Name	Description	CQM2	PFM2	EQM	PFM3
Temperature Sensors Characterisation	Characterise the temperature measurement errors of the flight and EGSE temperature sensors.	X	X	-	EGSE Sensor Only
Cooler Pump Characterisation	Characterise the MGSE L0 pump strap conductance and establish the relation between the pump temperature and its internal power dissipation. The later will be used for future correlation to estimate the total cooler load based on the pump temperature.	X	X	X	5mW case only
Level-0 Detector Strap Characterisation	Characterise the MGSE L0 detector strap conductance and evaluate the heat load flowing on the strap.	X	-	-	-
Level-1 Characterisation	Characterise the MGSE L1 strap conductance and evaluate the heat load flowing on the strap.	-	X	-	X
JFET Isolation Characterisation	This test assesses the level of isolation of the JFET CFRP supports.	X	-	-	-
Cooler Recycling	The operation profile of the cooler during recycling is assessed during this test.	X	X	X	Manual and Automated
Cooler Hold Time Characterisation	This test assesses the instrument hold time performance for a given thermal environment. This test was carried out as part of the thermal balance tests below.	X	X	X	X
Thermal Balance Test 1 OFF Mode	Test with nominal thermal environment - calibration cryostat temperature stages maintained at ~1.7K and ~4K and instrument in OFF mode.	X	X	-	-
Thermal Balance Test 2 Cold Case	Test with nominal thermal environment - calibration cryostat temperature stages maintained at ~1.7K and ~4K.	X	X	-	X
Thermal Balance Test 3 Hot Case	Test with a warmer thermal environment (as worst case) with the calibration cryostat temperature stages maintained at ~2K and 4K to 5.5K.	X 2K/4K	X 2K/5.5K	-	1.89K/4.3K
PTC Testing	Evaluate the performance of the Photometer BDAs active control.	-	-	-	X

Table 3-1 – List of tests carried out during the CQM/PFM/EQM Test Campaigns

3.1.1.1 CQM1/2 Test Campaign Summary

All thermal tests were carried out successfully but inconsistencies were detected in some of the temperature sensors data. Specific tests were carried out during the CQM2 test campaign to check whether sensor self-heating could be the reason for these erroneous data but the results remained unsatisfactory. Further analysis was carried out to identify others possible causes for these inconsistencies [AD8] and specific tests were defined to help characterise any error present in the flight and EGSE temperature sensors as part of the PFM2 test campaign. Correlation of the CQM test data with the thermal model was not possible but preliminary observations provided important information about the instrument thermal performances. These are summarised below:

- During the CQM1 test campaign, large temperature drops (about 0.3K) were observed at both the photometer and spectrometer enclosures L0 straps interfaces. As a result, both the thermal interfaces and the interbox L0 strap were modified, on time to be tested as part of the CQM2 test campaign. The temperature drops were successfully reduced to about 0.05K for the nominal thermal environment (1.7K/4K).

- The cooler cold tip and PLW detector temperatures were measured during the CQM2 test campaign for the nominal thermal environment (1.7K/4K) and the five detectors connected to the 300mK busbar (of which, four were STM BDAs). A 35mK temperature drop was observed between the cooler and the PLW BDA (drop along the 300-mK busbar + an assumed 10mK temperature drop internal to BDA) in excess of the maximum 20mK specified (and 10mK as a goal). Corrective measures were taken and a higher purity copper was used for the flight 300-mK busbar.

- Two thermal balance test cases were run during the CQM2 test campaign, from which the cooler total load and hold time could be estimated, as summarised in the table below. It is important to note that the following restrictions were applicable to these preliminary measurements:

    - While the parasitic loads from the cooler and the 300mK busbar were flight representative, four of the BDA were STM.

    - The CQM cooler was slightly undercharged.

    - MGSE L0 straps (non-flight representative) were used to recycle the cooler as the flight straps would not fit inside the calibration cryostat.

Thermal Test Cases	Nominal Case	Hot Case
Thermal Environment during Recycling	1.7K/4K	1.7K/4K
Thermal Environment during Operation	1.7K/4K	2K/4K
Temperature of Evaporator at end of condensation phase	~2K	~2K
FPU Temperature at L1 IF	4.39K	4.39K
Average L0 Enclosures Temperature	1.76K	1.98K
Estimated Evaporator Average Load (*)	24-26uW	36-40uW
Cooler Hold Time	49 hr	36 hr
Cooler cold tip Temperature	277mK	286mK
PLW Detector Temperature	310mK	350mK

Table 3-2 – Instrument Level Performances during CQM2 Test Campaign

(*) The cooler load was estimated using the cooler pump characterisation test. This approach was later found to underestimate the cooler total load by up to 14% [AD16].

A specific test was carried out as part of this CQM2 test campaign to characterise the overall conductance of the PJFET CFRP isolation supports. These test data could not be used for thermal correlation at the time because of inconsistencies present in some of the temperature sensor readings. During the PFM2 test campaign, these temperature inconsistencies were characterised [AD4] and the test data from the CQM2 test campaign could therefore be used again for correlation.

Additional information about the CQM1/2 test campaign results and analysis can be found in the thermal test report [AD1].

3.1.1.2 PFM2 Test Campaign Summary

All tests were carried out successfully during the PFM2 test campaign with the exception of the "L0 Detector Strap Characterisation" test. The EGSE heater required for this test was found to be in open circuit following cooldown.

A characterisation test was carried out on the flight prime/redundant and EGSE temperature sensors. As a result, DC offset and self-heating errors could be quantified for some of the flight sensors explaining some of the inconsistencies observed during the previous CQM1/2 test campaigns.

Additional observations could be made about the instrument thermal performance as part of this test campaign, these are summarised below:

- The L0 interbox strap performance remained good. A further reduction of the temperature drop at the boxes interfaces could be observed (from 0.05K to <0.02K) following the change from stainless steel isolation supports to CFRP supports. This means that the two boxes are now isothermal to within about 10mK.

- The new 300mK busbar (made of higher purity copper) was used for this test campaign and the temperature drop between the cooler cold tip and the BDAs was successfully reduced from 35mK (measured during the CQM2 campaign) to about 10mK for the nominal thermal environment of 1.7K/4K, which is well within the 20mK requirement. As the flight cooler and all five flight detectors were used during this test campaign, the measured performance (if correct) was a good indication of the instrument in-flight capability for this specific thermal environment. Please note that the measured temperature for the PLW detector appears to be cooler that the evaporator cold tip itself. This is not possible and further analysis is required to understand where this inconsistency is coming from.

- Two thermal balance test cases were run from which the cooler total load and hold time could be estimated, as summarised in the Table 3-3 below.

- The measured cooler hold time for the nominal 1.7K/4K thermal environment was about 50h25min which is within the required 46 hr. Please note however that the L0 straps were not flight representative. Further analysis is required that will compare the conductance of these MGSE L0 straps with the measured flight ones to estimate the in-flight performances of the instrument. A "hot" case was also run to provide a second data point for correlation with the instrument thermal model.

- The following instrument operational heat loads were measured for both the cold and hot cases:

    - Heat load flowing on the L0 pump strap,

    - Heat load flowing on the L1 strap. This heat load will be correlated in order to estimate how much heat load is coming from the calibration cryostat cryo-harnesses and radiation.

As these are not representative of the Herschel flight cryostat, the current value does not allow a proper verification of the instrument L1 operational load.

Thermal Test Cases	Cold Case	Hot Case
Thermal Environment during Recycling	1.7K/4K	2K/5K
Thermal Environment during Operation	1.7K/4K	2K/5K
Evaporator Temperature at end of condensation phase	~2.1K	~2.1K
Pump Temperature at end of condensation phase	~41.7K	~43.4K
FPU Temperature at L1 IF	4.3K	4.8K
Average L0 Enclosures Temperature	1.72K	1.95K
Estimated Evaporator Average Load (*)	26-29uW	30-33uW
Cooler Hold Time	50h25min	34h30min
Cooler cold tip Temperature	288.5mK	294.9mK
PLW Detector Temperature	283mK	-
PMW Detector Temperature	303.7mK	-
PSW Detector Temperature	293.3mK	-
SLW Detector Temperature	299.9mK	341.5mK (**)
SSW Detector Temperature	299.5mK	341.5mK (**)
Measured Pump L0 Heat Load [+/-5%]	2.1 mW	-
Measured FPU L1 Heat Load [-17%/+38%]	10.2 mW	-

Table 3-3 – Instrument Level Performances during PFM2 Test Campaign

(*) Here again, the cooler load was estimated using the cooler pump characterisation test. This approach was later found to underestimate the cooler total load by up to 14% [AD16].

(**) The cooler cold tip was at 301.9mK and was slightly varying at the time the detectors temperature was measured.

Additional information about the PFM2 test campaign results and analysis can be found in the thermal test report [AD4].

3.1.1.3 EQM Test Campaign Summary

The main goal of the EQM level-testing was to assess the impact of instrument operational modes on its L1 thermal stability and hence on its overall thermal performances (in terms of cooler hold time and absolute detector temperatures). This test could not be carried out as the mass flow rate of the EQM cryostat L1 ventline was too different from the one that can be expected in the flight cryostat. Thermal balance testing was difficult as the stability requirements were hard to achieve in the EQM cryostat. This test however was an opportunity to check any potential anomalies of the instrument performances at system level. The following anomalies were observed:

- Inconsistencies present in some of the instrument temperature sensors reading – this problem had already been encountered at instrument test level during the CQM2 test campaign and is now understood ([AD8], [AD4]).
- Some observations suggested that the instrument L1 temperature may be strongly linked to the cryostat cryo-cover temperature. The reasons for this behaviour still require to be clarified.

3.1.1.4 PFM3 Test Campaign Summary (New Section)

All thermal tests were carried out successfully during the PFM3 test campaign; a summary of the main test outcomes is given below. Additional information about the PFM3 test campaign results and analysis can be found in the thermal test report [AD17].

The instrument L1 heat load was re-evaluated after the change of the L1 cone support from CFRP back to SST and was estimated to be about 25.5mW (versus 9.2mW -17%/+38% measured during the PFM2 test campaign for a similar environment with all mechanisms OFF). Two additional tests were carried out with a different cryostat environment to help the correlation with the thermal model. The correlation of the L1 heat load is currently on-going.

The cooler performance was initially verified using the manual recycling script. Some degradation in the cooler performance during recycling was detected i.e. for a similar L0 interface temperature, the evaporator only managed to reach 2.3K at the end of the condensation phase versus 2.1K during PFM2. An NCR has been raised (HR-SP-RAL-NCR-150v2) and analyses (summarised in [AD18]) were carried out to determine the origin of this under-performance. It is currently believed that a degradation of the bolted interface conductance between the cooler heat switches and the L0 GSE straps is most likely causing the cooler to run warmer during recycling. As there isn't any temperature sensor fitted on the heat switches however, it is currently impossible to fully discard a degradation of others components internal to the cooler (such as flexible straps, bolted interfaces and/or heat switches conductances).

The cooler hold time performance was checked during the 'nominal' thermal balance test (1.7K/4K) and for recyclings completed as part of the performance testing. The measured hold time is consistent with the hold time measured during the PFM2 test campaign for a similar thermal environment i.e. no change in cooler total heat load has been detected. This is also confirmed by the fact that the cooler cold tip was running at the same temperature as during PFM2 (~288.5mK).

A new script has been developed to allow an automated and optimised cooler recycling during which the pump temperature is maintained to or above 45K. The script has been successfully tested and will be used from now on to recycle the cooler as it simplifies the process and ensures that it is repeatable. Additional fine tuning of the control loop parameters is required to ensure that the pump remains above 45K for the whole duration of the condensation phase.

Some testing with the PTC has been carried out. The results are still being analysed, an update will be given on the day of the SVR2 review if more information is available then.

A new algorithm has been used to evaluate the Photometer Bolometer Detector Array temperatures based on the dark load curve measurements. The measurements taken as part of the PFM2 test campaign have been re-evaluated to ensure consistency when comparing them with the ones obtained during the PFM3 test campaign. Despite this, the estimated BDA temperatures (both for the photometer and the spectrometer) remain inconsistent (they suggest negative temperature drops along the 300mK busbar) and the data measured during the PFM3 test campaign do not match the PFM2 test data (for a similar environment). The PFM3 SLW data even read temperatures lower than the cold tip itself.

Some more testing has been carried out with the instrument calibration sources and mechanisms, some in flight representative AOT modes. A maximum temperature increase of 0.55K was recorded for the SMECm (although the CQM SMEC is still in used) and 0.12K for the BSM (although this was for short duration tests only). Under all operating mode tested to date, the SOB never warmed up by more than 55mK.

The temperature drop across the Photometer JFET L3 interface (across the isolation joint as well as the bolted interface) was also quantified for the first time. It appeared to be larger than anticipated but there are some uncertainties as to where this drop is taking place however (across glued joint and/or bolted interface). It is important to note that there is no L3 temperature stage in the calibration cryostat and that an improvised L3 has been implemented i.e. connecting the JFETs to the cryostat radiation shield (running at the same temperature as the HOB) through GSE straps.

3.1.2 List of tests still to be done (Updated for PFM4 Test Campaign)

The thermal tests defined in the Table 3-4 are required to complete the instrument level verification of SPIRE thermal performance.

Test Name	Description	Applicable Requirement	Priority	Comments
Thermal Balance Test Nominal Environment	This test will ensure that the instrument thermal performances have not degraded following the cold vibration testing. This test will also be used to check that the change in L0 strap MGSE was successful in restoring the cooler performance (during recycling) to normal.	All IRD-COOL-R09	**High**	**Health Check**
L1 Strap Characterisation	This test will assess any change in the instrument total L1 parasitic load and check how repeatable the calibration cryostat thermal environment is.	IRD-STRC-R14 IRD-STRC-R15	**High**	**Inputs to thermal model correlation**
Cooler Recycling in Close-Loop	This test will allow the fine-tuning of the control loop parameters used to maintain the pump temperature at ≥ 45K during the cooler recycling.	IRD-COOL-R08	**High**	**Cooler performance Fine-tuning**
Flight Temperature Sensors Characterisation	The flight sensors (prime and redundant) should be checked out for DC offset and self-heating errors (wherever possible given the ground equipment and flight hardware limitations).	IRD-STRC-R07 IRD-CALS-R15 IRD-SMEC-R13 IRD-COOL-R18	**High**	**Required for SCAL and the evaporator sensor as a minimum**
PTC Operation	This test will assess the impact of the PTC operation on the cooler total load and detector temperature stability.	IRD-COOL-R02 IRD-COOL-R04 IRD-COOL-R05	**High**	**Input to thermal model correlation**

Test Name (Ctd)	Description	Applicable Requirement	Priority	Comments
Mechanisms and Calibration Sources Operation	This test will assess the impact of mechanisms and calibration sources operation on the instrument L1 temperatures, as well as confirm (TBC) the instrument L1 heat load for the various operational modes.	IRD-BSMP-R11 IRD-BSMP-R12 IRD-CALP-R12 IRD-CALS-R09 IRD-CALS-R12 IRD-CALS-R16 IRD-SMEC-R11	**High**	**Testing with the SMECm and BSM required**
300-mK Decontamination Test Case	This test evaluates the possibility of warming the 300mK system to >4K in an attempt to remove any Helium contamination.	N/A	**High**	**Will confirm the unit level testing results**
Thermal Balance Test Hot Environment	This test will verify the instrument thermal performance under warmer conditions.	All	**Medium**	**Inputs to thermal model correlation**
L0 MGSE Strap Characterisation	GSE Heaters have been fitted to the new GSE straps so that they can be used for additional characterisation of the instrument thermal performance if required.	N/A	**Medium**	**For troubleshooting**

Table 3-4 - List of tests still to be done

Additional information about the PFM4 thermal test specification can be found in [AD23].

3.2 Instrument Thermal Requirements Verification Status (Updated)

Requirement Name	Requirement	Measured Value	Comments	Applicable Report-Procedure	Status
IRD-BSMP-R11	The BSM structure or mirror shall rise by no more than 1K from the nominal temperature of the surrounding after an hour of operation in any mode	A maximum BSM temperature increase of 0.122K has been recorded during the 6mA PCAL Flash	Within specification to date	SPIRE-RAL-REP-002684 [PFM3 Test Report - Section 4.8.2]	Test where the BSM is run continously for a minimum of 1 hour still to be completed.
IRD-BSMP-R12	The dissipation should be within specification given in RD15 - 3mW maximum mean power dissipation during 46-hr operation	3.47mW Mean power for POF3 mode which is the worse case mean dissipation	In excess of 0.47mW Dissipation figures measured at unit level only.	Email from Brian Stobie on 09/02/04 PFM Powers II.xls	Confirm plan for verification at instrument level if necessary
IRD-CALP-R10	The thermal conductance between the photometer calibrator body and the SOB shall be >2mW/K	N/A as no temperature sensor on PCAL	Verified by design.	N/A	
IRD-CALP-R12	Shall be within the specification given in RD15 - 0.033 mW maximum mean power dissipation during 46-hr operation	2.91mW dissipated for standard PCAL flash 3.8 mA, 30 sec per hour => 0.0527 mW	In excess by 0.0197 mW	SPIRE-RAL-REP-002684 [PFM3 Test Report - Section 4.8.1]	
IRD-CALS-R09	Shall be within the specification given in RD15 - 2mW maximum mean power dissipation during 46-hr operation	For SCAL2 @ 85.5K 15mW peak for 2min Then 1.087V, 2.12mA => 2.31 mW	In excess by 0.31 mW	SPIRE-RAL-REP-002684 [PFM3 Test Report - Section 4.8.1]	Tested at unit and instrument level but in-flight the required SCAL temperature (hence dissipation) will be driven by telescope emissivity
IRD-CALS-R12	The SCAL enclosure shall provide an attachment point for a thermal strap to avoid the SCAL to warm up its environment by more than 1K	N/A	In specification Maximum SCAL enclosure warmup experienced in operation < 0.1K (for SCAL2 @ 80.8K) SCAL4 warms up by as much as 0.55K	SPIRE-RAL-REP-002684 [PFM3 Test Report - Section 4.8.2]	

Requirement Name	Requirement	Measured Value	Comments	Applicable Report-Procedure	Status
IRD-CALS-R15	Thermometers shall be provided on the spectrometer calibrator as specified in section 3.5.12	Sensor fitted	Sensors checked for self-heating, DC offset and calibration errors.	SPIRE-RAL-REP-002534 [PFM2 Test Report - Section 4.3.2]	**Self-Heating:** SCAL = 2.6mK SCAL2 = 13.9mK SCAL4 = 17.9mK **DC Offset:** SCAL2 = 4mK SCAL4 = -5.3mK
IRD-CALS-R16	Warmup Time: Stable nominal operating temperature to be reached in less than 30 min(reqt) 15 min (goal). Cooldown Time from nominal operating temperature to <10K: 3hr (reqt) 30 min (goal)	SCAL2 - Warmup < 10min SCAL 2 - Cooldown from 80K takes 50min	In specification	SPIRE-RAL-REP-002684 [PFM3 Test Report - Section 4.8.1]	
IRD-COOL-R01	The 3He cooler, in conjunction with the associated 300 mK architecture, shall maintain all bolometer detector assemblies at less than 310 mK – goal 300 mK	PFM2 / PFM3 PLW = 293 / 292.3 PMW = 298 / 291 PSW = 300 / 294 SLW = 299.9 / 283 SSW = 299.5 / 302 Both for evaporator temp of 288.5mK	According the BDA EIP there is a 7-12mK temperature drop inside the BDA. This suggest negative temperature drop along the 300mK busbar which is inconsistent. Data inconsistent from PFM2 to PFM3 and SLW reads cooler than the cooler itself.	SPIRE-RAL-REP-002684 [PFM3 Test Report - Section 4.6]	More calibration required during PFM4
IRD-COOL-R02	Desirable to vary the temperature of the detectors up to 320mK and below 300mK if permitted by thermal busbar.	TBC	Some PTC testing was completed during PFM3, data are being analysed		More test required during PFM4
IRD-COOL-R03	Maximum of 20mK (Goal = 10mK)	TBC	Inconsistent BDA temperature prevent this requirement from being verified at the moment	Correlation report (SPIRE-RAL-REP-002723) still being produced	
IRD-COOL-R04	Evaporator cold tip should drift by no more than 0.1mK/h under active control	TBC under flight condition	0.025mK/hr measured at unit level for stable nominal environment 1.7K/4K without active control	HSO-SBT-RP-118 [p28]	Can only be fully validated in the flight cryostat
IRD-COOL-R05	10uK.Hz-1/2 in a 0.1-10 Hz band	TBC			Can only be fully validated in the flight cryostat

Requirement Name	Requirement	Measured Value	Comments	Applicable Report-Procedure	Status
IRD-COOL-R07	Minimum of 10uW at 290mK	280mK measured at unit level for nominal 1.7K/4K environement under 10uW	In specification.	HSO-SBT-RP-118, Issue 1 [p28]	
IRD-COOL-R08	Minimum of 46 hrs	50h25min	Within requirement, for the nominal thermal environment of 1.7K/4K. Effective evaporator Temperature at end of condensation was 1.89K and pump temperature was 41.6K at start of cryo-pumping. Unchanged for PFM3	SPIRE-RAL-NOT-002588 [PFM2 Flight Predictions - Section 3.1.4]	Can only be fully validated in the flight cryostat
IRD-COOL-R09	Maximum of 2 hours	Less than 2 hrs during PFM2 but issue encountered during PFM3	New L0 GSE straps will be implemented for PFM4. The cooler recycling time will need checking again then to confirm the cooler performance is nominal.	SPIRE-RAL-MEM-002693 [SPIRE Cooler Performance Degradation During PFM3 Testing]	Can only be fully validated in the flight cryostat as fight L0 strap don't fit in the RAL calibration cryostat
IRD-COOL-R11	Cooler L0 Strap conductance Requirement of 150mW/K at 1.7K	Evap strap ~130 mW/K at 1.7K (out of spec) Pump strap ~203 mW/K at 1.7K (in spec)	Measured at unit level as the strap don't fit in the RAL calibration cryostat. Measurements confirmed by second unit level test.	Cardiff Thermal Test Report - PFM L0 Strap [15/11/05]	
IRD-COOL-R12	Pump L0 load in operation 2mW maximum	2.1mW	Close to requirement, for the nominal thermal environment of 1.7K/4K.	SPIRE-RAL-NOT-002588 [PFM2 Flight Predictions] Cooler total operational load confirmed for the nominal environment (1.7K/4K)	
IRD-COOL-R13	Total Energy 860J	927J	Depending on the cooler hold time performance in flight, this value could be adjusted to remain with the 860J allocated.	HSO-SBT-RP-118, Issue 1 [p28]	Also dependent on pump temperature control approach
IRD-COOL-R18	Thermometers shall be provided on the cooler as necessary to monitor its behaviour and operation (see section 3.5.12). Absolute temperature measurement on evaporator cold tip shall be 1% (<3mK) with a resolution of 1mK.	Sensors fitted	Sensors checked for self-heating, DC offset and calibration errors.	SPIRE-RAL-REP-002534 [PFM2 Test Report - Section 4.3.2]	

Requirement Name	Requirement	Measured Value	Comments	Applicable Report-Procedure	Status
IRD-DETP-R13	The thermal dissipation and parasitic load at 300mK shall be within the specification given in RD15	The cooler total load has been estimated to 29.6μW. 12μW should be accounted for the cooler parasitic load, which gives a total 300mK system parasitic load of 17.6μW (including 300mK busbar parasitic loads ~2μW).	Within requirement, for the nominal thermal environment of 1.7K/4K.	SPIRE-RAL-NOT-002588 [PFM2 Flight Predictions] Cooler total operational load confirmed for the nominal environment (1.7K/4K) Cooler modeling verified	
IRD-DETS-R14	The thermal dissipation and parasitic load at 300mK shall be within the specification given in RD15				
IRD-FTB-R05	The dissipation of the JFET amplifiers shall be heat sunk to the L3 cryostat stage and shall be within the specification given in RD15 - 42mW and 14mW maximum mean power dissipation during 46-hr operation for PJFET and SJFET respectively	56.64 mW for PJFET and 15.17 mW for SJFET has been measured at unit level.	These values includes a +/-5% error bar. They are exceeding the allocated 42 and 14mW power dissipation.	Email from Doug Griffin on 25/07/06 HR-SP-RAL-RFW-005v1 Email from Doug Griffin on 01/08/06 JFET Allocation.xls	
IRD-FTB-R11	The JFET structure shall be thermally isolated from the Herschel optical bench with specification given in RD15 - Less than 0.005W/K (goal 0.002W/K).	TBC	Preliminary correlation results suggest that this requirement has been met for both JFETs.	Correlation report (SPIRE-RAL-REP-002723) still being produced	
IRD-FTB-R12	The JFET structure shall be thermally connected to L3 via a strap with interface specification given in RD15 - 0.138W/K at 15K	TBC		Correlation report (SPIRE-RAL-REP-002723) still being produced	
IRD-SMEC-R11	The dissipation should be within specification given in RD15 - 3.2mW maximum mean power dissipation during 46-hr operation	Results from unit level testing to be checked	Flight unit has not been tested at instrument level yet		Confirm plan for verification at instrument level if necessary
IRD-SMEC-R13	The SMEC shall provide thermometers as detailed in section 3.5.12.	Sensor fitted	These sensors cannot be checked for self-heating, DC offset and calibration errors.		
IRD-STRC-R05	The inside and outside of the box shall have a finish with a low emissivity. At least e = 0.2. Some parts of the structure walls may be blackened as part of the straylight control.	TBC but test in Herschel STM cryostat suggest higher radiation load than anticipated	The L1 heat load has been measured at instrument level both during PFM2 and PFM3.	Correlation report (SPIRE-RAL-REP-002723) still being produced	

Requirement Name	Requirement	Measured Value	Comments	Applicable Report-Procedure	Status
IRD-STRC-R07	The structure subsystem shall provide thermistors and associated wiring to allow the temperature of critical parts to be monitored during in-flight operations – see section 3.5.12	Sensors fitted	Some of the prime and redundant flight sensors have been checked for self-heating, DC offset and calibration errors whenever possible.	SPIRE-RAL-REP-002534 [PFM2 Test Report - Section 4.3.2]	
IRD-STRC-R14	The conductance from the level 2 to level 1 stage shall be within the specification given in RD15.	Out of spec as L1 cone support changed back to SST after cold vibration failure	The L1 heat load has been measured at instrument level both during PFM2 and PFM3.	Correlation report (SPIRE-RAL-REP-002723) still being produced	
IRD-STRC-R15	The SPIRE Optical Bench shall be connected to the L1 stage with a thermal conductance meeting the requirements in RD15 - 1.5W/K at 5.5K	0.73 W/K at 4.3K measured during PFM3	Within specification as the measured value also included the L1 bolted interface conductance (which isn't part of this interface)	SPIRE-RAL-REP-002684 [PFM3 Test Report - Section 4.2.1]	
IRD-STRP-R04	The outside of the box shall have a finish with a low emissivity. At least e = 0.2. The inside of the box shall have a low reflectivity finish on all non-optical surfaces.	N/A	Visual inspection.	N/A	
IRD-STRP-R09	The conductance along the photometer detector box mechanical support from L1 to L0 shall be within the specification set in RD15	Exact value TBC		Correlation report (SPIRE-RAL-REP-002723) still being produced	
IRD-STRP-R10	The photometer box shall be connected to the spectrometer box with a strap meeting the conductance requirements in RD15 - 0.05W/K at 1.7K	Exact value TBC		Correlation report (SPIRE-RAL-REP-002723) still being produced	
IRD-STRS-R04	The outside of the box shall have a finish with a low emissivity. At least e = 0.2. The inside of the box shall have a low reflectivity finish on all non-optical surfaces.	N/A	Visual inspection.	N/A	
IRD-STRS-R08	The conductance along the spectrometer detector box mechanical support from L1 to L0 shall be within the specification set in RD15	Exact value TBC	Awaits thermal model correlation.	Correlation report (SPIRE-RAL-REP-002723) still being produced	

Requirement Name	Requirement	Measured Value	Comments	Applicable Report-Procedure	Status
IRD-STRS-R09	The spectrometer box shall be connected to the cryostat L0 stage with a strap meeting the conductance requirements in RD15 - 0.15 W/K at 1.7K	Enclosure strap ~237 mW/K at 1.7K (in spec)	Measured at unit level as the strap don't fit in the RAL calibration cryostat. Measurements confirmed and validated by second unit level test.	Cardiff Thermal Test Report - PFM L0 Strap [15/11/05]	

Table 3-5 – Instrument Thermal Requirements Verification Matrix

4. Open issues and anomalies

4.1 Open Issues

4.1.1 SPIRE Flight Thermal Model Correlation

To maximise the chances of Herschel providing the required 1.7K/4K thermal environment, a number of unit level requirements must be met. Some have already been validated through direct observations of the instrument performance during the instrument level testing (such as the L0 interbox strap and characterisation of the L0 pump strap heat load), but some remained to the validated as part of the thermal model correlation, such as:

- Instrument L1 isolation support conductance (IRD-STRC-R14) and L1 isolation joint conductance (IRD-STRC-R15). The correlation of the SST L1/L0 supports and L1 FPU isolation joint has been completed, a thermal correlation report is being produced [AD19].
- JFET isolation supports conductances (IRD-FTB-R11) – the correlation of the PJFET isolation support has been completed, a thermal correlation report is being produced [AD19].
- In addition, the instrument L1 cone support has recently been changed from CFRP back to stainless steel following a cold vibration failure. The impact of this change will have to be assessed as part of the PFM3 instrument level test campaign. During the PFM3 test campaign, the L1 heat load characterisation test suggested a higher L1 heat load than anticipated (25.5mW during PFM3 versus 10mW during PFM2 for same environment and with no mechanisms dissipation – note the only difference was the L1 cone support changed from CFRP back to stainless-steel).

<u>**Note:**</u>

A 24mW L1 parasitic load was characterised by Astrium as part of the Herschel STM testing with a SPIRE MTD. The following limitations were applicable during this test:

- The MTD was shiny (SPIRE has been alochromed),
- The MTD was fitted with SST L1 supports but no L0 stage (SPIRE has a SST cone and two CFRP A-frames),
- The JFET units were present but not thermally connected to the FPU (no parasitic load coming from L3),
- The HOB and instrument shield were running at 13-14K with a mass flow rate of 2.34mg/s,
- There was no mechanisms dissipation.

The Astrium test suggests that the L1 heat load measured as part of the PFM3 test campaign at RAL is more likely than the original 10mW measured during PFM2. The correlation of the instrument L1 heat load is still on-going.

The correlation of the SPIRE thermal model is expected to be completed by mid-February 2006 the latest. Preliminary results of the correlation will be part of the Science Verification Review presentation material if available then. The correlation of instrument thermal model with the PFM2 test data was completed in February 2006 (with the exception of the some of the instrument operational heat loads) and a technical note with updated flight predictions [AD16] was distributed in March 2006. The following activities remain to be done for the correlation to be complete:

- L1 heat load.

4.1.2 L0 FM Strap Conductance - confirmation of test results

While the flight L0 straps could not be used as part of the instrument level testing[2], their thermal conductance has been measured at unit level. The test results [AD11] currently show that both the pump and enclosure L0 straps are within the specification while the evaporator strap is 14% under the specification (130mW/K measured versus 150mW/K required). A second unit level testing has been completed since; the new results matched the data obtained during the first unit level test, thus validating the test setup and results (as some issues had initially been encountered during the first test).

4.1.3 Instrument Operational Mode Scenarios and Thermal Stability

An update of the instrument power dissipation budgets is presented in appendix 6 for the worse instrument operating mode. A 0.5mW total mechanism increase has been estimated for the photometer mode while a 1.5mW increase has been estimated for the spectrometer mode. The following points should be noted however:

- These cases are worse cases – it is unlikely that the instrument will operate the BSM in the chop-jiggle mode or the SMEC R1000 mode for the whole 46hr period for example.
- An increase in L1 heat load could degrade the instrument performance if as a result, the Herschel L1 interface temperature increases too much.
- The results from the thermal model correlation will provide an additional insight as to how much margin is currently available for the total L1 heat load – L1 heat load still on-going.
- The stability requirement at the evaporator cold tip (IRD-COOL-R05) remains to be verified and it will have a direct impact on the PTC use, hence on the cooler hold time (IRD-COOL-R02) and (IRD-COOL-R04).

It is important that in the near future, more realistic instrument operational mode scenarios be devised and used as an input to the thermal model (after correlation) in order to analyse the impact of mechanism operation on the instrument thermal stability and overall performances.

[2] *As they would not fit inside the calibration cryostat.*

4.2 Anomalies

SPIRE L1 Operating Heat Load	The results from the EQM testing suggested that the instrument L1 temperature may be strongly linked to the EQM cryostat cryo-cover temperature (by radiation). Note: no correlation work was carried out for this test campaign. Recent results from the Herschel STM campaign and the SPIRE PFM3 test campaign also suggest a higher L1 heat load than originally anticipated. The SPIRE thermal model correlation is progressing well, the correlation of the instrument L1 heat load being the remaining outstanding item. A new version of the Herschel thermal model has been released. New predictions for the SPIRE L1 operating load should be available by the end of October 2006.
Cooler Performance Degradation during Recycling	A degradation of the cooler performance during recycling was detected as part of the PFM3 test campaign. It is currently believed that a degradation of the bolted interface conductance between the cooler heat switches and the L0 GSE straps is most likely causing the cooler to run warmer during recycling. A new set of L0 GSE straps will be used for the PFM4 test campaign. This should help validating the above statement and the cooler performance are expected to return to normal.
300mK Temperature Inconsistencies	Some inconsistencies remain in the measurement of the 300mK system. Current measurements suggest a negative temperature drop along the 300-mK busbar and the PFM3 data for SLW are reading cooler than the cooler cold tip. This therefore suggests that: - either the cooler cold tip temperature contains some self-heating - either the BDA temperature predictions are not well calibrated It is important to note that the cold tip temperature (and predicted total operational heat load) didn't change from the PFM2 to the PFM3 test campaign, whereas the BDA temperature did. Could this suggest that the BDA are sensible to environmental factor such as helium film…? Some analyses has been done with the SPIRE thermal model and a correlation of the BDA temperatures to +/-2mK could be obtained by: - adding an offset of -10mK to the cooler cold tip (or +10mK to all detectors) for the PFM2 test data - adding an offset of -13mK to the cooler cold tip (or +13mK to all detectors) for the PFM3 test data These predictions therefore suggest that a net 10-15mK offset is present on the 300mK data but also that a cold tip temperature of 278.5mK is somewhat inconsistent with the predicted total evaporator load of 29.6uW (according to the cooler unit level test result).
Flight Temperature Sensor DC Offset	Errors in the instrument temperature readings as large as 90mK have been quantified during PFM2. Their cause is now well understood but cannot be corrected for at this stage as it would require to change the way the sensors are readout by the flight electronics (change from DC excitation voltage to an

	AC excitation voltage) [AD4]. A 0.1K error in the temperature measurements of the FPU has been found acceptable. It was suggested however that the temperature offsets of SCAL be calibrated against the operating currents so that a correlation can be made once in the flight cryostat. Self-heating of the evaporator cold tip will be checked during PFM4 if possible.
Temperature Drop across the PJFET L3 Isolating Interface	During PFM3, the temperature drop across the PJFET and its L3 strap in the RAL calibration cryostat has been found to be larger than anticipated: 1.5K versus 0.4K. The following limitations were applicable however: - the measurement also contain the bolted interface – it is therefore impossible to exactly know how much is due to the isolation joint - the sensors absolute accuracy was +/-0.25K.

5. Recommendations for further data analysis and test

5.1 Further Analysis

The correlation of the instrument level test data with the thermal model is underway and currently has the highest priority. Once an acceptable level of agreement has been reached between the thermal model and the test data, new flight prediction thermal analyses with the Herschel cryostat thermal model will be required. These analyses should include some transient analyses to investigate the thermal stability performances of the instrument for the various operational modes. Please note that a new issue of the Herschel thermal model is not expected before end of February 2006 so Issue 4 will be used in the meantime [AD12]. Finally, a new SPIRE Interface Thermal Model should be created (based on the correlated SPIRE detailed thermal model) and should be delivered to Astrium for future analyses at spacecraft level.

A new thermal model of Herschel (Issue 4.6) has been released by ESA on 13/09/06. This new model will be used in conjunction with the correlated SPIRE thermal model to obtain updated predictions of the instrument flight performance (steady-state and transient analysis). Predicted date for thermal performance flight prediction update – End of October 2006 (TBC).

The delivery of an updated reduced version of the SPIRE flight thermal model has been discussed with Astrium in June 2006 and was initially set for the end of August 2006. This will only be possible once the SPIRE L1 heat load correlation has been completed. Predicted date for delivery of updated correlated SPIRE model - End of October 2006 (TBC).

5.2 Further Testing

Any remaining instrument level testing (ILT) has been defined in section 3.1.2 of this document. Additional thermal tests have been defined for the Instrument System Level (IST) testing. More details can be found in the thermal section of the SPIRE System Level Test Plan [AD20].

6. SPIRE Flight Interface Temperature - Predictions (New Section)

6.1 Herschel Thermal Interface Temperatures

The Herschel STM test campaign was completed in October 2005 and provided preliminary insight about the interface temperatures SPIRE is likely to experience in flight. The following sections provide a summary of the expected interface temperatures for the L0, L1 and L2/3 temperature stages. More details about the Herschel STM Interface test results can be found in [AD22].

6.1.1 L0 Interfaces

Based on the Astrium test report [AD22], the following should be achieved in flight for the L0 interface temperatures:

- The HTT will be operated at <1.67K in order to fulfil the PACS level 0 requirement,
- The SPIRE L0 detector pod conductance at 1.65K is 40 mW/K,
- The SPIRE L0 pump pod conductance at 1.65K is 46 mW/K,
- The SPIRE overall L0 evaporator pods conductance at 1.65K is 212 mW/K.

Based on this and the SPIRE L0 operational heat loads, the Herschel L0 flight interface temperatures can be estimated as described in Table 6-1.

	Conductance	L0 Operational Heat Load (**)	I/F Temperature (*)
	[mW/K]	[mW]	[K]
SPIRE L0 Detector I/F	40	1	1.695
SPIRE L0 Pump I/F	46	2	1.713
SPIRE L0 Evaporator I/F	212	15	1.741

(*) Based on HTT running at 1.67K
(**) Based on Goal Operating heat loads for which the instrument has been designed

Table 6-1 – SPIRE Predicted Flight L0 Interface Temperatures

Notes: The pump and enclosure operational heat loads are highly dependent on the FPU L1 temperature.

6.1.2 L1 Interface

Based on the Astrium STM test report [AD22], the following interface temperatures should be achieved in flight for the L1 temperature stage:

Operational L1 Heat Load	Mass Flow Rate	HOB Temperature	L1 I/F Temperature	MTD Temperature
[mW]	[mg/s]	[K]	[K]	[K]
24	2.3-2.4	13-14	4.75	4.93
29.5	2.3-2.4	13-14	5.2	5.4
34	2.3-2.4	13-14	~5.7	~5.9

Table 6-2– SPIRE Predicted Flight L1 Interface Temperature

6.1.3 L2/3 Interfaces

Based on the Astrium STM test report [AD22], the following interface temperatures should be achieved in flight for the L2/3 temperature stages:

JFETs	Operational Heat Load	Mass Flow Rate	HOB Temperature	L3 I/F Temperature
-	[mW]	[mg/s]	[K]	[K]
Photometer	47	2.33	14	17.2
Spectrometer	27	2.34	14.6	16.6

Table 6-3 - SPIRE Predicted Flight L2/3 Interface Temperatures

7. Appendices

7.1.1 Instrument Power Dissipation Budgets

Mechanism/Calibration Sources/JFET	Allocated Budgets [RD15]	Dissipation Measured at Unit Level		Comment
PCAL	33uW	52.7uW	Standard PCAL Flash (~2.91mW for ~30 sec every hour)	Maximum mean power dissipation during 46hr operation.
SCAL	2mW	2.3mW		Maximum mean power dissipation during 46hr operation.
BSM Photometer Mode	3mW	3.47mW		Maximum mean power dissipation during 46hr operation. Assumption: the worse case operational mode is used for the whole 46hr period (POF3: Chop-Jiggle Mapping).
BSM Spectrometer Mode	0.2mW	0.8mW		Maximum mean power dissipation during 46hr operation.
SMEC Actuator	2.6mW	2.1mW		Maximum mean power dissipation during 46hr operation. Assumption: the worse case operational mode is used for the whole 46hr period (R1000).
SMEC Encoder	0.5mW	1.523mW		Maximum mean power dissipation during 46hr operation.
SMEC LVDT	0.1mW	0.112mW		Maximum mean power dissipation during 46hr operation.
Total L1 Dissipation Budget Photometer Mode	3.033mW	3.523mW		In excess of 0.49mW.
Total L1 Dissipation Budget Spectrometer Mode	5.4mW	6.85mW		In excess of 1.45mW.
PJFET	42mW	56.64mW		Maximum power dissipation during 46hr operation.
SJFET	14mW	15.17mW		Maximum power dissipation during 46hr operation.

Table 7-1 – SPIRE Power Dissipation Budgets {AD13], [AD14], [AD15].