SPIRE Science Verification Review

RAL

January 26, 27 2005

Optical Performances

Marc Ferlet

Document Number: SPIRE-RAL-REP-002572

Contents

1. Introduction and scope

This document summarises the present status of the verification of the SPIRE instrument optical performances. List of the relevant requirements is given in section 2. Section 3 gives the principal results obtained so far with respect to individual optics subsystem level and optics-related instrument level requirements. A few anomalies found are reported in section 4. Some recommendations for priority data analysis and future tests are discussed in section 5. Finally, references for the background technical documentation are to be found in section 6.

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

The optics-related requirements to be evaluated are listed in the table below; along side the relevant SPIRE model which has allowed/will allow their partial or complete verification. The requirement identifiers are taken from AD1.

Requirement Name	Description	Verification Method	Model	Test ID	Upper Links
IRD-OPTP-R00	Compatibility with Herschel telescope	Design analysis Instrument level alignment verification Instrument level performance tests	AM CQM	ILT_ALIGN ILT_PERF	IID-A-SECT4.3.1
IRD-OPTP-R01	Nominal final focal ratio	Design analysis	N/A	N/A	
IRD-OPTP-R02	Variation in focal ratio	Design analysis Instrument level alignment verification Instrument level performance tests	AM CQM PFMI PFMII	ILT_ALIGN ILT_PERF	IRD-PHOT-R10
IRD-OPTP-R03	Distortion	Design analysis Instrument level alignment verification Instrument level performance tests	AM CQM PFMI PFMII	ILT_ALIGN ILT_PERF	IRD-PHOT-R10
IRD-OPTP-R04	Anamorphism	Design analysis Instrument level alignment verification Instrument level performance tests	AM CQM PFMI PFMII	ILT_ALIGN ILT_PERF	IRD-PHOT-R03
IRD-OPTP-R06	Image quality	Design analysis Instrument level alignment verification Instrument level performance tests	AM CQM PFMI PFMII	ILT_ALIGN ILT_PERF	IRD-PHOT-R03 IRD-PHOT-R04 IRD-PHOT-R05
IRD-OPTP-R08	In-band straylight	Design analysis Instrument level performance tests	CQM PFMI PFMII	ILT_PERF	IRD-PHOT-R04
IRD-OPTS-R01	Nominal final focal ratio	Design analysis	N/A	N/A	
IRD-OPTS-R02	Variation in focal ratio	Design analysis Instrument level alignment verification Instrument level performance tests	AM CQM PFMI PFMII	ILT_ALIGN ILT_PERF	
IRD-OPTS-R03	Distortion	Design analysis Instrument level alignment verification Instrument level performance tests	AM CQM PFMI PFMII	ILT_ALIGN ILT_PERF	
IRD-OPTS-R04	Anamorphism	Design analysis Instrument level alignment verification Instrument level performance tests	AM CQM PFMI PFMII	ILT_ALIGN ILT_PERF	IRD-SPEC-R05
IRD-OPTS-R06	Image quality	Design analysis Instrument level alignment verification Instrument level performance tests	AM CQM PFMI PFMII	ILT_ALIGN ILT_PERF	IRD-SPEC-R05 IRD-SPEC-R06 IRD-SPEC-R07
IRD-DETS-R07	Detector angular	Design analysis Subsystem	N/A	N/A	IRD-SPEC-R05

Requirement Name	Description	Verification Method	Model	Test ID	Upper Links
	response	acceptance data package			
IRD-DETP-R07	Detector angular response	Design analysis Subsystem acceptance data package	N/A	N/A	IRD-PHOT-R06
IRD-STRC-R01	Alignment of the instrument w.r.t. the FIRST optical axis	Design analysis Instrument alignment verification	AM CQM	ILT_ALIGN	IID-A-SECT5.3.2.1
IRD-STRC-R04	Optics and associated sub-system alignment	Design analysis Instrument alignment verification	AM CQM	ILT_ALIGN	
IRD-STRC-R08	Attenuation of radiation from cryostat environment	Design analysis Instrument level performance tests	CQM	ILT_PERF	IRD-PHOT-R04 IRD-PHOT-R05 IRD-SPEC-R17
IRD-STRP-R02	Optics and filters alignment	Design analysis Instrument alignment verification	AM CQM	ILT_ALIGN	
IRD-STRP-R03	Array module alignment	Design analysis Instrument alignment verification	AM CQM	ILT_ALIGN	IRD-PHOT-R16
IRD-STRP-R06	Attenuation of radiation from common structure environment	Design analysis Instrument level performance tests	CQM	ILT_PERF	IRD-PHOT-R04 IRD-PHOT-R05
IRD-STRS-R02	Optics alignment requirements	Design analysis Instrument alignment verification	AM CQM	ILT_ALIGN	
IRD-STRS-R03	Array module alignment	Design analysis Instrument alignment verification	AM CQM	ILT_ALIGN	
IRD-STRS-R06	Attenuation of radiation from 4-K environment	Design analysis Instrument level performance tests	CQM	ILT_PERF	IRD-SPEC-R17
IRD-PHOT-R02	FoV	Design analysis Instrument level alignment verification Instrument level performance tests	CQM PFM I PFM II	ILT_ALIGN ILT_PERF	SRD R7
IRD-PHOT-R03	Beam FWHM	Design analysis Instrument level Instrument level performance tests	CQM PFM II	ILT_PERF	SRD R1
IRD-PHOT-R10	Field distortion	Design analysis Instrument level alignment verification Instrument level performance tests	AM CQM PFM I PFM II	ILT_ALIGN ILT_PERF	SRD R6
IRD-PHOT-R16	Co-alignment	Design analysis Instrument level alignment verification Instrument level performance tests	AM PFM I PFM II	ILT_ALIGN ILT_PERF	SRD R15
IRD-SPEC-R04	FoV	Design analysis Instrument level performance tests	PFM I PFM II	ILT_PERF	SRD R16
IRD-SPEC-R05	Beam FWHM	Design analysis Instrument level performance tests	PFM I PFM II	ILT_PERF	SRD R16

3. Test results and conclusions

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

Tests relevant to optical alignment (ILT_ALIGN in table above), mostly for AM and CQM models are discussed in RD1 and RD2.

Test relevant to in-band optical performances (ILT_PERF in table above) test on CQM and PFM1 are discussed in RD4 and RD5 with support from the specific characteristics of the optical set-up of the SPIRE test facility, described in RD3.

More details on the SPIRE test campaign details on the can be found at the following link:
http://scott1.bnsc.rl.ac.uk:8080/hcss/test_area/index.htm .

3.2 Subsystem requirements tested at instrument level and their verification status

The table below summarised the optics subsystem requirements and their present status.

Requirement Name	Description	Verification status
IRD-OPTP-R00	**Compatibility with Herschel telescope**	Nominally by design HSO telescope taken HSO axis and pupil simulated during AM warm and cold alignment activities as reference for pupil alignment (internal/external).
IRD-OPTP-R01	**Nominal final focal ratio**	Taken as F/5 by design. Not derived (yet) from measurement.
IRD-OPTP-R02	**Variation in focal ratio**	Ok by design. To be derived from future Phot full FoV mapping and PSF measurements
IRD-OPTP-R03	**Distortion**	Ok by design. To be derived from future Phot full FoV mapping measurement
IRD-OPTP-R04	**Anamorphism**	Ratio of axes length in assumed generally elliptical beam pattern found <~10% for PLW from CQM (at FoV centre) so compliant to the 6/5 max ratio ; to be confirmed by PFM2 PLW measured beam data. To be analysed for PSW. PMW affected by the anomaly during PFM2 so possibly not relevant.
IRD-OPTP-R06	**Image quality**	Strehl ratio >99% at 250um over full Phot FoV; derived from measurement during AM warm alignment. Not derived (yet) from in-band measurement (through-focus).
IRD-OPTP-R08	**In-band straylight**	To be discussed in the spectral & throughput performances document.
IRD-OPTS-R01	**Nominal final focal ratio**	Taken initially as ~F/5 but final design gives ~4.85+/-0.1 for SLW and 4.35+/-0.1 for SSW (uncertainty is variation across FoV). From PFM1: measured to be between 4.5 and 5 for SLW; measured to be between 4 and 5 for SSW.
IRD-OPTS-R02	**Variation in focal ratio**	From above: Ok by design and ok as derived from PFM measurements.
IRD-OPTS-R03	**Distortion**	Ok by design; estimated to <~5% from field mapping.
IRD-OPTS-R04	**Anamorphism**	From PFM1: found <~10% for the all pixels tested in SSW and SLW. Some uncertainty remains due to test source fluctuations and shape at different wavelengths.
IRD-OPTS-R06	**Image quality**	Strehl ratio >95% at 250um at FoV centre; derived from measurement during AM warm alignment. Improved to >97% after astigmatism correction in Spec optical train for PFM. Not derived (yet) from in-band measurement (through-focus).
IRD-DETS-R07	**Detector angular response**	By design in Spec BDAs EIDP Modal content to be further investigated (see section 5.2) at different wavelengths and correlated with spectral bandpass measurement

Requirement Name	Description	Verification status
IRD-DETP-R07	**Detector angular response**	By design in Phot BDAs EIDP Modal content to be further investigated (see section 5.2) at different wavelengths and correlated with spectral bandpass measurement
IRD-STRC-R01	**Alignment of the instrument w.r.t. the FIRST optical axis**	TBC by FPU structure characteristics
IRD-STRC-R04	**Optics and associated sub-system alignment**	Test on AM warm and cold for pupil alignment (after vibrations) + warm CQM => ok within spec. Test warm on PFM (before vibrations) -> ok well within spec. No filters, BDAs, or BSM.
IRD-STRC-R08	**Attenuation of radiation from cryostat environment**	TBC by structure design
IRD-STRP-R02	**Optics and filters alignment**	Test on AM warm and cold for pupil alignment (after vibrations) + warm CQM => ok within spec. Test warm on PFM (before vibrations) -> ok well within spec. No filters, BDAs, or BSM.
IRD-STRP-R03	**Array module alignment**	
IRD-STRP-R06	**Attenuation of radiation from common structure environment**	TBC by structure design
IRD-STRS-R02	**Optics alignment requirements**	Test on AM warm and cold for pupil alignment (after vibrations) => ok within spec. Test warm on PFM (before vibrations) => ok well within spec No filters, BDAs, or BSM.
IRD-STRS-R03	**Array module alignment**	
IRD-STRS-R06	**Attenuation of radiation from 4-K environment**	TBC by structure design

3.3 Instrument-level requirements and their verification status.

The table below summarised the higher level relevant requirements and their present status.

Requirement Name	Description	Verification Status
IRD-PHOT-R02	**FoV**	4x8arcmin^2 nominal from design. Used as-is during AM activities but not quantitatively assessed. Not assessed in-band (yet).
IRD-PHOT-R03	**Beam FWHM**	PSW: TBC (measured during PFM2 but final value not yet derived) PMW: TBC but potential discrepancy due to PMW anomaly (see section 4) PLW: 30+/-4.8arcsec at 432um (measured during CQM2 tests), equivalent to 34.7+/-5.5 at 500um. Uncertainty to be reduced by analysis of PFM2 data. A priori, compliant wrt spec: 36arcsec at 500um
IRD-PHOT-R10	**Field distortion**	To be derived from future Phot full-Fov measurement.
IRD-PHOT-R16	**Co-alignment**	Not directly measured during AM activities as BDAs and filter not present. Used as design guideline in BDA/Phot detector box alignment hardware design (see SPIRE-RAL-NOT-002344 issue 1.0 (15/03/05)). Good general alignment (quantitatively TBC) found between PLW and PSW. PMW appeared not perfectly co-aligned during PFM2, likely due to the anomaly (see section 4).

Requirement Name	Description	Verification Status
IRD-SPEC-R04	**FoV**	2.6arcmin diameter nominal from design. Not used or assessed during AM activities (on-axis use only) + not present in CQM. Spec field mapping during PFM indicate FoV is at least 2.6arcmin (although small continuous vignetting occur right from the FoV centre) for both SSW and SLW.
IRD-SPEC-R05	**Beam FWHM**	SSW: 16+/-2arcsec at 250um (extrapolated from value derived from PFM1 measurement) So compliance with spec of 18arcsec at 250um. SLW: measured during PFM1 >40arcsec below ~310um and <30arcsec above 500um So not compliant with the spec of 25arcsec at 350um but the spec does not take into account the multi-modal behaviour of the detector+coupling optics (broadband waveguide + feedhorn).

4. Open issues and anomalies

- ***Spatial response of PMW array:***

During PFM2 test campaign, it was observed a different spatial response. It acted as PMW channel was affected by field dependent aberrations inducing change in shape of the PSF from pixel to pixel alongside an estimated longer in-band relative depth-of-focus and relatively large (in fraction of pixel) misalignment wrt PSW and PLW arrays.
After inspection after the test campaign, a bent/curved dichroic (in reflection for PMW) was found. The design expects a flat reflecting surface while a possible powered element was present during the PFM2 tests in front of PMW BDA. This can qualitatively explain the effects seen.
More quantitative estimations (comparison measured data/optical simulations) will be performed to assure that no other PMW BDA specific effects are to be the cause. Meanwhile the dichroic in question has been replaced by a flat one at ambient.

- ***Global illumination of the Phot arrays:***

A non-uniform illumination pattern of the Phot arrays has been found. The issue under investigations in an attempt to discriminate the possible cause: individual detector response, test source field flatness, extra misalignment at operating conditions or internal vignetting of Phot optical path at FoV edge not previously found.

- ***Spec Channel fringing:***

The presence of low and high frequency channel fringing in the Spec SSW and SLW interferogram signals was detected during PFM1 testing. It seems to appear when looking at cold, spatially and spectrally broad source (not found when bright monochromatic point sources are used).
In-field ghost images were expected and simulated in both SSW and SLW in particular due to the presence of the additional field lenses in front of both BDAs and could lead to some channel fringing. And modelling of some Spec characteristics have led to good matching of other features of Spec interferogram signal such as the baseline variation and decentring (from internal apodisation, vignetting and SMEc localised small decentre and tilt).

But here the exact source of the different channel fringing effects is not entirely clear: supplementary reflections detector/lens, OPD-dependent out-of-field stray (internal ?) path are among the alternative explanations.
Corrective action such as the development and use of an AR coating on the Spec field lenses will reduce the magnitude of the spatially overlapping ghost images and therefore reduce the effect of the channel fringing.

5. Recommendations for further data analysis and test

5.1 Recommended data analysis

- ***PFM2 spatial data:***

Most point source beam scans and peak-ups, monochromatic and broadband, as well as pupil scan profiles at different wavelength are to be analysed in order to characterise the individual pixel spatial response (PSF shape for derivation of FHWM, anamorphism, etendue).
NB: The Phot arrays were only partially active so distortion and variation at the Phot FoV scale can not be retrieved from PFM2 test data set.

- ***Through-focus beam scans***:

Further analysis of this data set could be used to retrieve any eventual residual in-band relative defocus between arrays (i.e. longitudinal co-alignment), within Phot and Spec respectively, as well as in-band Strehl ratio (instead of the wavelength scaling technique used at the moment from Warm Alignment image quality test in the VNIR), including filter and detectors, from the axial variations of measured focal plane irradiance.
NB: Optical phase retrieval (including the effect of the coupling detector-feeding optics) could be performed but not expected to give high due to large depth-of-focus and natural long-wavelength blurring

- ***Merging of pupil scans and beam scans data:***

When measured with same calibration source at same wavelength, subtracting the measured focal plane pixel beam pattern back projected on the external pupil from the pupil scan data in order to obtain an estimate of the telescope pupil illumination.
NB: This is limited for the moment to a reduced number of wavelengths (1 for Spec during PFM1, 2 for Phot during PFM2).

5.2 Recommended tests

- ***Systematic mapping of the Phot FoV:***

The availability of the complete live Phot arrays for PFM3 performance test campaign would allow the Phot FoV mapping (extent, distortion). This would be performed by systematic series (along chop and jiggle axes as well as FoV corners) of point source peak-ups, moved by/from external test set-up with recording of the source pointing.
NB: for Spec, this was done nearly completely during PFM1 performance test campaign.

- ***Extension of the spatial characterisation tests (beam scans & peak-up):***

Extension of the standard spatial beam scan test with monochromatic point source to more wavelengths in-band for Phot and Spec would allow a more spectrally continuous derivation of the main characteristics (PSF width and shape) in each band and compared to alternative derivation of the wavelength-dependent throughput (e.g. from spectral bandpass measurement).
This needs the use of several wavelengths per Spec or Phot bands when available by the calibration source (FIR laser). The use of low power but detectable spectrally tunable photomixing source, tested during PFM2, can complement the FIR laser at the longer wavelength regions (in PLW and SLW bands).

- ***Extension of the pupil scan:***

The pupil scan test is at the moment performed by scanning a simulated point source at the SPIRE external exit pupil (matching HSO telescope secondary) only in one direction (along Z_{esa}), horizontal in the test configuration. In order to extend the verification the illumination of this circular external pupil for both Spec and Phot, it is recommended to perform the test as well the pupil scan in the orthogonal direction (Y_{esa}). A simple scheme for the implementation of this manual test in the present test set-up is being investigated.

- ***Polarisation response:***

To avoid spurious effect from source already polarised such as the FIR laser and supplementary polarisation rotation induced by the test set-up optics, it is recommended to perform the polarisation test with the broadband calibration source (HBB), typically in point source mode towards co-aligned Spec or Phot pixels. Implementation and procedure have already been developed accordingly.
NB: This is not directly called by any optics or instrument level requirements but its interest lies in the potentiality that a change in response as function of the polarisation angle could inducing some modulation (eventually spatially-dependent) in in-band throughput.

6. References

6.1 Applicable documents

AD1 SPIRE-RAL-PRJ-00034 issue 1.3 (14/07/05)

6.2 Reference documents

RD1 SPIRE STM alignment test campaign: Phot Hartmann test, Spec Hartmann test, cold stop alignment verification (05/03) + SPIE vol 5487 pp448-459 (06/04)

RD2 SPIRE-RAL-NOT-001807 issue 2.0 (07/07/04)

RD3 SPIRE-RAL-NOT-002006 issue 2.0 (09/01/06)

RD4 SPIRE-RAL-NOT-002211 draft 0.3 (23/02/05)

RD5 SPIRE-RAL-NOT-002460 issue 1.1 (11/01/06)