DOCUMENT

SPIRE Products Explained

Prepared by	Ivan Valtchanov
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1 Introduction

This document explains the content of the various products available in the *Herschel* Science Archive (HSA) for science observations performed the SPIRE instrument. There are indeed multiple ways to access the SPIRE products and multiple choices on which products to use. Moreover, the products for the two sub-instruments: the SPIRE Photometer and the SPIRE Fourier-Transform Spectrometer, are different. We describe here what is contained in these choices, and highlight which products are the most useful for the different types of observations and science.

Section 2 gives an overview of the possible product flavours offered in the HSA. Those are then described on more details in Sections 3–10. Section 11 will provide recommendations on the best product to use for a particular observing mode. Finally, we give in the appendix further information regarding meta-data and FITS keywords contained in the SPIRE products, as well as how the products can be used in other standard software, like python/astropy.

Note that this document does not discuss how the products were made, the pipelines and the different calibration schemes. The reader should consult the SPIRE Handbook and the SPIRE Data Reduction Guide for further details. A good starting point with link to different sources of information is the SPIRE web portal[1].

Detailed description of the different products, including generic *Herschel* products, can be found in the Products Definition Document. Even lower level details are provided in the automatically generated Product Definition Supplement.

2 SPIRE products in the HSA

The bulk of the SPIRE products present in the HSA are the result of the processing of the telemetry data with the standard pipeline coded in the Herschel Interactive Processing Environment (HIPE). Those products are also referred to as Standard Product Generation (SPG) output, and are described in the following section.

Additional SPIRE products are also served by the HSA:

- User-Provided Data Products (UPDPs) are products delivered by external users, and corresponding in most cases to observations performed in the context of Guaranteed or Open Key Programmes. These are further described in Sec. 8.
- Highly-Processed Data Products (HPDPs) are products derived from standard pipeline products, either as complementary information relevant to the archive users, or as improvement of the pipeline products themselves, usually curated by instrument experts. These are further described in Sec. 9.
- Ancillary Data Products (ADPs) are products with complementary or historical information relevant to SPIRE, both from scientific or engineering perspective. Some of these are available in the SPIRE calibration context (described in Sec. 5) but for convenience some of the products are provided as ADPs. The ADPs are further described in Sec. 6.

[1]Available at: https://www.cosmos.esa.int/web/herschel/spire-overview

All SPG products provided by the HSA are multi-extension FITS files, while the additional products may be in other formats. Moreover, the UPDPs, HPDPs and ADPs may not only be in the form of images, spectra or spectral cubes, but can also be catalogues, models, etc.

3 Description of the SPIRE pipeline products

All *Herschel* SPIRE data come from the HSA in the form of a directory-tree structure organised by processing level. When inspected in HIPE, those levels are referred to as contexts. A context is a special kind of product, linking other products in a coherent description, and can be thought of as an inventory or catalogue of products. The SPIRE processed observation consists of many such contexts enclosed within one Observation Context. The Observation Context is therefore a product container, which is comprised of various layers of science data, auxiliary data, calibration data, and other information about the observation, as illustrated in Fig. 1.

Figure 1: The structure of an Observational Context.

Each SPIRE Observation Context is the outcome of the Standard Product Generation (SPG), run in bulk with a given version of the Herschel Common Software System (HCSS). The SPG version, present in the metadata of any Context, reflects the HCSS version of the reprocessing.

For SPIRE, the vast majority of the products served in the HSA have been processed with version 14.1 of the HIPE. Only SPIRE Photometer mosaic maps (Level 3 context) had to be reprocessed with HIPE 14.2 to fix a bug that affected how the error map of the mosaic was calculated.

The SPIRE data has been processed by the pipelines in increasing levels of processing, Level 0 being the lowest level products available to archive users, up to the Level 3. Science data are found at Levels 1 and above.

3.1 SPIRE Photometer products

A short description of each of the sub-contexts of a SPIRE Photometer observational context is provided below:

- **Level 0**: Raw data, formatted from the raw telemetry by an external pre-processing stage.
- **Level 0.5**: Produced by processing the raw Level 0 data through the Common Engineering Conversion (Level 0 - Level 0.5) Pipeline. The Level 0.5 data are the uncalibrated, uncorrected timelines measured in Volts.
- **Level 1**: Flux calibrated and *destriped* timelines for each scan line and each bolometer. For observations that are part of Level 2.5 maps, the destriped timelines are derived from the combined maps.
- **Level 2**: The calibrated and destriped timelines from Level 1 are directly projected on sky maps with default pixel size of (6, 10, 14) $''$/pixel for (250, 350, 500) μm bands. Point-source and extended-source calibrated maps for the three Photometer bands are available at this level. For Solar System Objects, point-source calibrated maps in the moving frame of the target are also provided.
  For extended-source calibrated maps with high signal-to-noise, hi-resolutions (HiRes) maps produced with Richardson-Lucy deconvolution are also available. The HiRes method typically increases the resolution of the image by a factor of 2.
  All extended-source calibrated maps at level-2 and above have their zero-level offset derived from *Planck*-HFI.
- **Level 2.5**: Maps are produced using the combined destriped Level 1 timelines of Parallel mode observations in separate nominal and orthogonal scan directions. In some cases, when there is a suitable overlap, SPIRE-only observations at single scan directions and/or cross-scans are also combined in Level 2.5 maps.
- **Level 3**: A mosaic with direct re-projection of Level 2 and/or Level 2.5 maps over a large contiguous area.

The folder structure and filename patterns for each level are described in Table 1.

The structure of the FITS files from Table 1, for products at level1 and above, are given in Appendix A.1.

Table 1: The folder structure of an HSA tar file for the SPIRE Photometer. Note that the tar file will also contain a number of `XML` files, which are needed when using the files with the Product Access Layer in HIPE.

Folder	Sub-folder	Filename pattern
level0	*BuildingBlockProduct	hspire<OBSID>_<BBID><NNNN>_00rst_ID
level0_5	*EdpBlockContext	hspirephotometer<OBSID>_a103<NNNN>_10psp_ID
level1	*PointedPhotTimeline	hspirephotometer<OBSID>_a103<NNNN>_10psp_ID
level2	extdPxW	hspire<ARR><OBSID>_20pxmp_ID
	extdPxWdiag	hspire<ARR><OBSID>_20pdd_ID
	psrcPxW	hspire<ARR><OBSID>_20pmp_ID
	psrcPxWdiag	hspire<ARR><OBSID>_20pdd_ID
	ssoPxW	hspire<ARR><OBSID>_20ssopmp_ID
	ssoPxWdiag	hspire<ARR><OBSID>_20pmp_ID
	hiresPxW	hspire<ARR><OBSID>_20hirespxmp_ID
level2_5	Same folders as level2	Same pattern as Level 2 except *<OBSID>_25* instead of *<OBSID>_20*
level3	extdPxW	hspire<ARR>_30pxmp_*

Notes: PxW denotes any of the three arrays, PSW=250μm, PMW=350μm or PLW=500μm. <OBSID> is the decimal OBSID, <ARR> is the array name and can be one of *psw, pmw* or *plw*. The ID is a unique product identification number. <NNNN> stands for the line scan number.

3.2 SPIRE Spectrometer products

A short description of each of the sub-contexts of a SPIRE Spectrometer observational context is provided below:

- **Level 0**: Raw data, formatted from the raw telemetry by an external pre-processing stage.
- **Level 0.5**: Produced by processing the raw Level 0 data through the Common Engineering Conversion (Level 0 - Level 0.5) Pipeline. The Level 0.5 data are the uncalibrated, uncorrected timelines measured in Volts.
- **Level 1**: The voltage density interferograms (in V/Hz) per detector and per scan, forward or reversed.
  - **Sparse mode:** There is only one sub-product with interferograms for all detectors.
  - **Mapping:** There will be sub-products for each of the 4 (intermediate spatial sampling) or 16 (full Nyquist spatial sampling) jiggle positions and at each of the raster position.
- **Level 2**: Calibrated spectra or spectral cubes and their apodized versions.
  - **Sparse mode:** point-source and extended source calibrated spectra, averaged for all scans and for all detectors. For H+LR mode the spectra for both the HR and LR are provided.
  - **Mapping:** extended source calibrated hyper-spectral cubes, including their apodized versions as well as the individual scan-averaged detectors spectra at each jiggle and/or raster position, before their binning into a spectral cube. Two variants of cubes are provided: naive projection (may contain empty pixels) and convolution projection using the Gaussian beam approximation to redistribute the intensities. For H+LR mode the cubes for each HR and LR are provided. The cubes for SSW and SLW bands are provided separately as they have different sky pixel size and WCS.

Table 2: The folder structure of an HSA tar file for the SPIRE Spectrometer. Note that the tar file will also contain a number of `XML` files, which are needed when using the files with the Product Access Layer in HIPE.

Folder	**Sub-folders**	**Filename pattern**
level0	*BuildingBlockProduct	hspire<OBSID>_<BBID><NNNN>_00rst_<ID>
level0_5	*EdpBlockContext	hspire<OBSID>_a107<NNNN>_05level05blockcontext_<ID>
level1	Point_<NR>_Jiggle_<NJ>_<RES>/interferogram/	<prefix><OBSID>_a106<NNNN>_10sdi_<ID>
level2 (mapping)	<RES>_<ARR>_cube <RES>_<ARR>_cube_convol <RES>_<ARR>_spectrum2d	<prefix><OBSID>_spg_<ARR>_<RES>_20ssc_<ID> <prefix><OBSID>_spg_<ARR>_convol_<RES>_20ssc_<ID> <prefix><OBSID>_spg_<ARR>_<RES>_20spc_<ID>
	<RES>_<ARR>_cube_apod <RES>_<ARR>_cube_convol_apod <RES>_<ARR>_spectrum2d_apod	<prefix><OBSID>_spgApod_<ARR>_<RES>_20ssc_<ID> <prefix><OBSID>_spgApod_<ARR>_convol_<RES>_20ssc_<ID> <prefix><OBSID>_spgApod_<ARR>_<RES>_20spc_<ID>
level2 (sparse)	<RES>_spectrum_ext <RES>_spectrum_point	<prefix><OBSID>_a1060001_spg_<RES>_20sds_<ID> <prefix><OBSID>_a1060001_spg_<RES>_20spss_<ID>
	<RES>_spectrum_ext_apod <RES>_spectrum_point_apod	<prefix><OBSID>_a1060001_spgApod_<RES>_20sds_<ID> <prefix><OBSID>_a1060001_spgApod_<RES>_20spss_<ID>

Notes: <prefix> stands for *hspirespectrometer*, <ARR> denotes any of the two arrays, SSW or SLW, both are always present. <OBSID> is the decimal observation ID. <RES> can be either HR or LR, for observations in H+LR mode, both are present. The <ID> is a unique product identification number. <NNNN> stands for the scan number. <BBID> is the building block ID in level0. Files with "apod" in the name are for apodized (smoothed) versions of the products. For level-1, <NR> and <NJ> are the running numbers of each raster and jiggle position. For sparse mode <NR>=0 and <NJ>=0. For intermediate coverage maps <NR>=0 and there will be 4 folders with <NJ> from 0 to 3, while for full coverage maps <NJ> will be from 0 to 15. For raster observations <NR> will denote the corresponding raster position.

The structure of the FITS files from Table 2, for products at level1 and above, are given in Appendix A.2.

4 The SPIRE standalone browse products

The standalone browse products (SBP) correspond to an automated extraction of some of the results from the standard pipeline. The choice of the SBP was decided by instrument experts and the *Herschel* archive scientist. The main purpose of this subset is to allow a very quick access to pre-defined "default products", e.g. for proposal preparation, quick-look analysis or quick production of images or spectra for visualisation purposes. SBP are available for every observation in the HSA and can be accessed through the user interface by right-clicking on the displayed browse image. The SBP are delivered in a tar file.

For the SPIRE Photometer, the SBPs are the level2_5 extended-source calibrated maps with zero offsets derived through cross-calibration with *Planck*-HFI. If there is no level2_5 available then SBP are the level 2 maps.

For the SPIRE Spectrometer, the SBPs are the level2 point-source calibrated spectra for sparse mode and convolution projection cubes for spectral mapping observations.

Note that the subset may only be useful for a particular science case. If this is not the case, e.g. the scientist is interested in performing point source analysis on photometer maps, then the relevant observation context products need to be downloaded and used.

5 The SPIRE calibration products

Each SPIRE observation context downloaded from the HSA also contains the calibration tree and some auxiliary products. The calibration tree in an observation context only contains calibration files that are relevant for the particular sub-instrument, i.e. for a Spectrometer observation only the calibration files with relevance for the Spectrometer pipeline or data analysis are available. A standalone calibration tree can also be downloaded from the Herschel Science Centre[2] as a java archive file (with extension jar). The jar archives are similar to tar archive and can be un-archived with a similar command: for example, `jar xvf spire_cal_14_3`, which will extract the individual calibration products in a folder structure like this: `herschel/spire/ia/cal/data/SCal/`. The products are FITS files, tables or images, that are available in the calibration context in the tar file from the HSA, which in general can be opened with any FITS viewer (topcat, fv, ds9, Aladin, astropy.io.fits etc). The FITS files have all the relevant metadata keywords with descriptions and the table columns have the correct units, so these should be straightforward to use. Most of the calibration files are only useful for the low level pipeline processing (see e.g. SPIRE Data Reduction Guide.)

All calibration products and and their descriptions are listed in the SPIRE Calibration Products Table.

6 The SPIRE auxiliary products

The Auxiliary Products are a collection of tables containing information on how the observation was planned and carried out. These are Orbit files, Ephemerides, Spacecraft-related products such as the pointing products, the Spacecraft/instrument Alignment Matrix (SIAM), the uplink information, etc. More details on the auxiliary products are provided in the Products Definition Document, Table 6.1.

Some aux products are needed by the pipeline during the different levels of processing. For most data reduction, you are unlikely to need to work directly with the Auxiliary Product, but it is helpful to know what and where the usable information is located in this product in case of tailored reductions needing the same information as in the pipeline.

7 The SPIRE quality context

Quality Control (QC) was carried out incrementally on all SPIRE observations, excluding calibration observations. During the active phase of the *Herschel* mission, high level quality checks were performed at the *Herschel* Science Centre, in order to react and reschedule any observation that may have failed due to instrument or spacecraft commanding problems. The pipelines also calculate different QC parameters, which are described in greater detail in the SPIRE Quality Control Metrics document. The final thresholds, based on trend analysis on all observations, are

[2]The latest standalone SPIRE calibration tree is available at `http://archives.esac.esa.int/hsa/legacy/cal/SPIRE/user/`

incorporated in the pipeline and in the QC Metrics table. The QC parameters are calculated for all relevant products and the values are available in the corresponding metadata.

In the Quality Context, however, only those above the threshold are listed, together with a QC summary text message. For SPIRE observations, the HSA only shows the QC Summary Message in the QC Report block. Usually, QC Summary text only appears if there are some concerns with the science quality of an observation. The message can be informing of an effect with no significant impact on the science products (INFO), with potential minor impact on the science quality (WARNING) or major impact on the science quality (SEVERE).

INFO messages are when some QC parameters are slightly over the empirical thresholds.

WARNING messages are when there is potentially a significant pointing offset or some pipeline module is not optimally correcting some effects due to some peculiar conditions, e.g. the instrument is too cold or too warm.

SEVERE messages are usually for observations that are impossible to calibrate because non-standard instrument settings were used, as well as for spectroscopy observations known to suffer significant pointing offsets. In some cases, expert processing of the observation could remedy the quality problem, and these are provided as Highly Processed Data Products. This is indicated in the QC Summary message.

8 The SPIRE User Provided Data Products (UPDP)

UPDPs are provided by external users on a best effort basis, the complete list of products hosted in the HSA will increase with time. The UPDP main web page[3] provides a list of the currently available UPDPs. Each one should have a respective release note with details about the content of each delivered dataset.

One of the UPDPs we offer for SPIRE, however, was prepared by the *Herschel* Science Centre: the unaveraged level-2 spectra (`SPIRE NonAvgLevel2`). These are data products that have been fully processed with the SPIRE Spectrometer standard product generation (SPG) pipeline, except the averaging step has been omitted. This means that for each detectors in a given observation, the UPDP contains all of the individual forward and reverse scans. Only sparse mode observations are included in the UPDP generation. The purpose of these UPDPs is that in some cases, especially for very faint targets, some scans may be noisier and omitting them during the averaging step may lead to a final spectrum with lower or better behaved noise. The availability of the individual calibrated and unaveraged spectral scans allows for more elaborate analysis on reliability of faint features through bootstrap or jackknife techniques.

9 The SPIRE Highly Processed Data Products (HPDP)

Highly Processed Data Products (HPDP) are sets of products generated by expert scientists, generally from the *Herschel* Science Centre (HSC), the NASA *Herschel* Science Center (NHSC), and the Instrument Control Centres (ICC). The HPDPs improve upon the standard pipeline generated products or provide alternative products that are better for a particular science analysis.

[3] https://www.cosmos.esa.int/web/herschel/user-provided-data-products

The HPDP are available at the *Herschel* Legacy Archive Area[4] and here we list and briefly describe the currently available ones. Each sub-folder in the HPDP/SPIRE folder contains the products and a release note with some details on the method to generate the products and the actual products. Some release notes are a precursor of an imminent publication in astronomy-related journals where most of the details will be presented.

9.1 SPIRE Photometer

- **SPIRE Point Source Catalog (SPSC)**: The SPSC catalogue was obtained by a systematic and homogeneous source extraction procedure on all SPIRE maps. Each band is treated independently (no band-merging) and the result is a catalog with more than 1.6 million entries from maps covering $\sim 8\%$ of the sky. The release has an extensive Explanatory Supplement with more details on the production and the content of the products.
- **SPIRE hiRes maps**: A subset of 800 SPIRE high signal-to-noise maps at level2 and level2_5 were deconvolved using the good knowledge of the SPIRE beam. The procedure is based on the Richardson-Lucy deconvolution algorithm. Note that the maps are exact copy of those present in the observational context of each observation. They are provided as HPDPs for convenience.
- **SPIRE astrometry corrected maps**: based on the work for the SPSC, the astrometry of all SPIRE maps was estimated via stacking on WISE 22 μm sources. In cases when the stack signal matched well the SPIRE beam, the astrometry offsets were derived and those maps with more than $5''$ total offset were corrected. This included regeneration of level2_5 maps, if one or more of the combined maps was affected by a large offset. In total, 70 maps (level2 or level2_5) are provided in this HPDP. Note that this is not an exhaustive list of maps suffering large astrometry offsets: for galactic fields or fields with contaminations from bright extended sources, the stacking signal could not be fit with a beam, and consequently no offsets were derived.

9.2 SPIRE Spectrometer

- **SPIRE Spectral Feature Catalogue**: The SPIRE FTS Spectral Feature Finder is an automated finding and fitting process that aims to provide a data mining aid and starting point for more in-depth SPIRE Spectrometer analysis. The Release Note contains more details on the production and the products. A paper is under preparation, presenting the methods and the catalog (Hopwood et al, in preparation).
- **Background corrected spectra**: SPIRE Fourier Transform Spectrometer sparse mode observations cover all types of sources: point-like, extended and semi-extended. The targets, as proposed by the observers, may be embedded in a foreground or background emission. The standard pipeline processed data products were carefully analysed and those that were considered centred on point sources embedded in a background were further processed,

[4] http://archives.esac.esa.int/hsa/legacy/HPDP/SPIRE/

using the smoothed spectra of the off-axis detectors to remove the fore/background contamination from the central ones. In total, there are 310 sparse mode observations for which we applied the background subtraction. With some caveats these are considered higher quality science products than the default ones from the standard pipeline.

- **Re-gridded spectral cubes**: There are 22 SPIRE Spectrometer mapping observations that suffer from one or more individual spectra that have higher than expected spectral resolution. This is a processing artefact that affects the final quality of the cubes. This HPDP provides a reprocessing of those cubes by fixing the spectral resolution to the correct one of 1.2 GHz. In this regridding, one or more pixels (of low quality) can be lost at the edge of the map.
- **Corrected spectra for the calibration targets**: Point-source calibrated high-resolution SPIRE Spectrometer spectra of the primary and secondary calibration sources, which have received post-pipeline correction as described in Hopwood et al. (2015). The post-pipeline corrections included background subtraction, pointing offset correction and source size correction (with the semi-extended correction tool, SECT). Please refer to the paper and the Release note for more details.

10 The SPIRE Ancillary Data Products (ADP)

Ancillary Data Products (ADPs) are data (images, tables etc) generated in the course of the different phases of the *Herschel* mission which are not necessarily linked to a particular observation in the HSA. Some of the SPIRE ADPs are extracted from the products already available in the calibration tree attached to each observation.

The following lists the available SPIRE ADPs[5]:

- **Models for calibration sources**: these ADPs include models for the planets Mars, Uranus and Neptune; stellar models; thermophysical model predictions for many asteroids. The calibrator models entry page provides an entry point for accessing the available data.
- **SPIRE beam (PSF)**: these are the beam profiles and beam maps for both the Photometer and Spectrometer. The products are a copy of those available in the SPIRE calibration tree.
- **SPIRE Photometer filter transmission and aperture efficiency**: these files are a copy of those available in the SPIRE Calibration Tree. These are needed for colour-corrections and for predicting SPIRE fluxes from model SEDs.
- **SPIRE Spectrometer sensitivity and continuum offsets**: the additive continuum offsets and the sensitivity (encoded as 1-σ in 1 hour) for point and extended-source calibrated spectra, for high (HR) and low (LR) spectral resolution. These can be used in the error budget analysis, for instance for very faint targets the additive continuum offset may dominate the total uncertainty and has to be taken into account in the total error budget.
- **SPIRE Spectrometer diffraction loss correction**: The diffraction loss model is described in Caldwell et al. (2000) and the curves within the SPIRE Spectrometer bands are derived

[5] The ADP are available in the *Herschel* Science Centre legacy area:
http://archives.esac.esa.int/hsa/legacy/ADP/

and presented in Wu et al. (2013), Figure 4. The measured beam areas have to be corrected for the diffraction loss, when using the beam solid angle to convert from the point-source calibration to the extended-source calibration.

- **SPIRE On-board software**: compilation of Onboard Software (OBSW) versions that were prepared for and uploaded into the Data Processing Unit (DPU) of the SPIRE instrument in the course of the operation phase of the mission. Top level documents such as the OBSW user's manual, as well as the release notes, are provided.
- **SPIRE ICC health monitoring and trend analysis pages**: This is a copy of the original RAL SPIRE ICC website, which was used and maintained during Herschel Space Observatory operations (May 2009 - April 2013). The html pages contain various links to health monitoring logs, observing logs and trend analysis products.

11 Recommended SPIRE data products

If the Standalone Browse Products match the science case, as explained in Section 4, then this is the most straightforward way to get the best science grade data. If this is not the case, then in most cases, Level-2 or above are of a sufficient scientific quality to be used as a starting point for any further data analysis (e.g. photometry, line flux measurements, etc).

The exceptions are Level-3 maps, which are a mosaic of individual Level-2 maps. The individual maps are already binned on sky pixels, moreover they are not corrected for astrometry offsets or registered to have the same relative astrometry. Hence, the combined Level-3 map may not be of a sufficient science quality.

In the following we list the science readiness of the Photometer and Spectrometer products, as described in the SPIRE Quick Start Guide. More details, as well as examples and recipes on improving or converting the pipeline products to match a particular science case are given in the SPIRE Data Reduction Guide.

Detailed list of caveats is available in the Data Products Known Issues public page.

11.1 Photometer

All SPIRE Photometer products at Level 1 and above are science ready with the following caveats:

- Point-source calibrated timelines and maps provide monochromatic flux densities at 250, 350 and 500 μm, and are in units of Jy/beam for a source with $S_\nu \propto \nu^{-1}$ spectral shape. Colour corrections need to be applied for sources with different SEDs, as explained in the SPIRE Handbook.
- Extended-source calibrated maps provide monochromatic intensities at 250, 350 and 500 μm, and are in units of MJy/sr for a source with $I_\nu \propto \nu^{-1}$ spectral shape. The zero offsets of the maps are derived via cross-calibration with *Planck*-HFI. Colour corrections need to be applied for sources with different SEDs, as explained in theSPIRE Handbook.
  For maps with sizes comparable to the *Planck*-HFI beam of $4'$, as well as maps with strong surface brightness gradients, the derived zero-point offsets can be much more uncertain

that the estimated cross-calibration accuracy of 10%, especially at 250 μm, because of the extrapolation. These should be used with caution.

- The combined maps at Level 2.5 and Level 3 are not astrometrically corrected before the merging of the timelines or the mosaicking of the maps.
- Some huge Level 3 maps are split into smaller non-overlapping tiles, in order to provide FITS files with manageable size.

11.2 Spectrometer

All SPIRE Spectrometer products at Level 2 are science ready with the following caveats:

- The point-source calibration is only correct for spectra of sources with an intrinsic size much smaller than the SSW beam, i.e. $\lesssim 3''$ (this limit comes from the size of the primary calibrator, Uranus).
- The extended-source calibration is only correct for spectra of sources with an intrinsic size much larger than the beam, i.e. $\gg 42''$. Keep in mind the significant variation of the beam size with frequency (see figure on page 16), e.g. a source with size 35$''$ can be considered fully extended in the SSW band, while it is not in the SLW band.
- Sources with a size between point-like and extended, need special treatment to correct the calibration.
- If the correct calibration is used, the SLW and SSW spectra should agree in the overlap region between the frequency bands [944.0, 1017.8] GHz. For a true point-source, if there is a jump between the spectra this may be due to pointing offset or the presence of extended background or foreground emission. For the latter problem, the background may be subtracted using spectra from the surrounding detectors. For many sparse mode observations, background subtracted spectra are provided as highly processed data products in the HSA.

11.3 Using UPDP and HPDP

User Provided Data Products: in many cases the UPDP may have better science quality then that standard products from the pipeline (SPG). However, these should be considered with caution and after a carful reading of the release notes and the accompanying papers, as the processing may only be good for a particular science case. In addition, some of the UPDP have been processed with early versions of both the pipelines and calibration trees, and the products may suffer from problems that were fixed in more recent versions of the software and the calibration. This will also require a careful analysis of the products, their versions and the residual artefacts that may be present in the data.

Highly Processed Data Products: in most cases those HPDP that are alternative to the SPG ones are of a better science quality. This, however, is also a subject to the science case and a carful reading of the release notes is highly recommended. Usually the HPDP are produced with the most up to date pipelines and calibration.

Some HPDPs have no SPG alternatives, like the SPIRE Point Source Catalogue or the Spectral Feature Finder Catalogue. These catalogues were extracted in an automated or semi-automated way, so they are useful as a starting point but their use for scientific analysis should be critically scrutinised.

A Appendix

A.1 Structure of SPIRE Photometer FITS files at level1 and above

Each SPIRE Photometer product is stored in a multi-extension FITS file, compressed with `gzip`. The primary extension (zeroth extension) holds metadata related with the observation. Each keyword in the metadata has description and unit, when applicable. These should be self-explanatory. In cases for low level products, some internal metadata keywords which were used in HIPE were not directly translated to FITS keywords while saving the products. These metadata keywords appear as `META_XX`.

In the following tables we present the structure of the FITS files at level1 and above, as shown in Table 1.

Table 3: Structure of a Photometer level1 FITS file. Each scan line is in a different FITS file.

Ext. name	Comment
PRIMARY	This extension only contains the metadata for the observation.
mask	A table with the sample time (in seconds) and a column for each bolometer, including thermistors and resistors, with a mask value corresponding to which processing flags have been raised. For masks definition please check the SPIRE Data Reduction Guide.
temperature	A table with the sample time (in seconds) and a column for each thermistor channel temperature (in Kelvin).
signal	A table with the sample time (in seconds) and a column for the signal from every bolometer including both detector (in Jy/beam) and non-detector channels (thermistors, resistors, in Volts). The signal timelines are already *destriped* with the two-pass pipeline.
ra	A table with the sample time (in seconds) and a column for the RA on the sky (in degrees) for each detector.
dec	A table with the sample time (in seconds) and a column for the Dec on the sky (in degrees) for each detector.
angVelocity	A table with the sample time (in seconds) and a column for the telescope angular velocity in deg/s.
History	Toplevel history context, ignore.
HistoryScript	List of the pipeline tasks used to make the product.
HistoryTasks	List of tasks and their version.
HistoryParameters	List of the tasks parameters, including calibration products, used in the scripts.

Note: there could be a Serendipity Mode scan present at level1. These scans, recorded when the telescope was slewing, are deglitched but not destriped, so they should be used with caution or ignored. The FITS keyword `BBTNAME` in the Primary extension is `SpireBbPhotSerendipity` for these scans. If present, the serendipity scan is the last scan, i.e. the file with the highest `a103<NNNN>` number (see Table 1).

Table 4: Structure of a Photometer level2, level2.5 and level3 FITS file. The History-related extensions are described in Table. 3.

Ext. name	Comment
PRIMARY	This extension only contains the metadata for the observation.
image	The image produced by the corresponding pipeline: extended/point source calibration.
error	The error image, not available for hiRes maps.
coverage	The number of detector readouts in a pixel.
cfv	Only present in hiRes maps, the correction factor variance image (see the SPIRE Data Reduction Guide).
flag	The flag image, only present in level3 maps. Produced by the `mosaic` task in HIPE.
History	
HistoryScript	
HistoryTasks	
HistoryParameters	

Note: we intentionally do not provide the extension number as it depends on the type of the product and the processing. Only the Primary extension has a fixed index zero, for the rest of the extensions it is safer to use the name.

A.2 Structure of SPIRE Spectrometer FITS files at level1 and above

Each SPIRE Spectrometer product is stored in a multi-extension FITS file, compressed with `gzip`. The primary extension (zeroth extension) holds metadata related with the observation. Each keyword in the metadata has description and unit, when applicable. These should be self-explanatory. In cases for low level products, some internal metadata keywords which were used in HIPE were not directly translated to FITS keywords while saving the products. These metadata keywords appear as `META_XX`.

In the following tables we present the structure of the FITS files at level1 and above, as shown in Table 2.

Table 5: Structure of a Spectrometer level-1 FITS file. The interferograms for each detector are tables with 3 columns: "opd" – the Optical Path Difference in [cm], "signal" – the interferogram signal in [V] and "mask" – the mask array. For observations with the combined H+LR observing mode, there will be a separate folder with the interferogram file for each of the two resolutions: high (HR) and low (LR). Similarly for spectral mapping observations, there will be a separate folder for each jiggle and/or raster position. In the case of mapping observations using the H+LR mode, then there will be a separate folder for each raster, jiggle and spectral resolution.

Ext. name	Comment
PRIMARY	This extension only contains the metadata for the observation.
<SSSS>	Empty image extension where <SSSS> is the scan running number, starting from the last one.
SLWA1	The interferogram for detector SLWA1 at scan <SSSS> (forward or reverse).
SLWA2	The interferogram for detector SLWA2 at scan <SSSS> (forward or reverse).
...	
SSWG4	The interferogram for detector SSWG4 at scan <SSSS> (forward or reverse).
<SSSS-1>	empty image extension where <SSSS-1> is the scan running number.
SLWA1	The interferogram for detector SLWA1 at scan <SSSS-1> (forward or reverse) .
SLWA2	The interferogram for detector SLWA2 at scan <SSSS-1> (forward or reverse) .
...	
SSWG4	The interferogram for detector SSWG4 at scan <SSSS-1> (forward or reverse).
...	
0001	Empty image extension indicating the start of scan 0001.
SLWA1	The interferogram for detector SLWA1 at scan 0001 (forward or reverse) .
SLWA2	The interferogram for detector SLWA2 at scan 0001 (forward or reverse) .
...	
SSWG4	The interferogram for detector SSWG4 at scan 0001 (forward or reverse).
History	Toplevel history context, ignore.
HistoryScript	List of the pipeline tasks used to make the product.
HistoryTasks	List of tasks and their version.
HistoryParameters	List of the tasks parameters, including calibration products, used in the scripts.

Note: the empty image extension with the scan number contains a number of useful metadata, e.g. to tell if the scan is forward or reverse one can check `hdu[<SSSS>].header['SCNDIR']`.

Table 6: Structure of a sparse mode Spectrometer level-2 FITS file. The averaged spectrum datasets for each detector are the averaged forward and reversed spectra from all scans. These datasets are tables with 5 columns: “wave” – the frequency in [GHz], “flux” – the flux in [Jy] for point-source calibration or the intensity in [$\mathrm{W\,m^{-2}\,Hz^{-1}\,sr^{-1}}$] for extended source calibration, “error” – the standard error of the mean from all averaged scans (forward and reversed) with the same unit as the “flux”, “mask” is the mask array and “numScans” – the number of scans that were averaged. A file with the same structure will be present in each of the sub-folders for sparse mode in Table 2.

Ext. name	Comment
PRIMARY	This extension only contains the metadata for the observation.
0000	Empty image extension. Only used and needed by the Product Access Layer in HIPE. Can be ignored.
SLWA1	The averaged spectrum dataset for detector SLWA1.
SLWA2	The averaged spectrum dataset for detector SLWA2.
... SSWG4	The averaged spectrum dataset for detector SSWG4.
History	Toplevel history context, ignore.
HistoryScript	List of the pipeline tasks used to make the product.
HistoryTasks	List of tasks and their version.
HistoryParameters	List of the tasks parameters, including calibration products, used in the scripts.

Table 7: Structure of a mapping mode `spectrum2d` products (also called preCube products) for the Spectrometer level-2. These are the individual spectra before the binning (also called preCubes or `spectrum2d` datasets). A file with the same structure will be present in each of the “_spectrum2d” sub-folders for mapping mode in Table 2.

Ext. name	Comment
PRIMARY	This extension only contains the metadata for the observation.
spectrum2d	A table with all individual spectral datasets. The same columns as in Table 6 are present with some additional columns: “longitude” and “latitude” – the RA, Dec in [deg] of the spectrum, “detector” – the detector name, “resolution” – the calculated spectral resolution, “jiggId” – the jiggle index, “pointNum” – the raster index, and a few more auxiliary columns from the pipeline.

Table 8: Structure of a mapping mode Spectrometer level-2 hyper-spectral cubes FITS files. A file with the same structure will be present in each of the cube sub-folders for mapping mode in Table 2.

Ext. name	Comment
PRIMARY	This extension only contains the metadata for the observation.
image	The average flux within a sky pixel for the naive or convolution projection.
error	The standard error of the mean of all spectra within a sky pixel.
coverage	The number of spectra within a sky pixel (naive cubes) or the sum of the weighted contribution from all spectra (convolution cubes).
flag	Available for flagging but not used.