

DOCUMENT

PACS Products Explained

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1 Introduction

This document explains the contents of the products available in the Herschel Science Archive (HSA) for science observations performed with the PACS instrument. There are multiple ways to access the PACS products, and multiple choices on which products to use. Moreover, the products for the two sub-instruments – the 3-band photometer and the integral field spectrometer – are different. We describe here what is contained in PACS observations, and highlight which products are the most useful for the different types of observation and science. Sec. 2 gives an overview of photometer and spectrometer observations that are provided either via the HSA or directly from ESA web resources: the pipeline products (SPG products) and the Standalone Browse Products (SBPs), the calibration and auxiliary products, the quality report (QCR), the User-Provided Data Products (UPDPs), the Highly-Processed Data Products (HPDPs), and the PACS Ancillary Data Products (ADP) are covered in Secs 2 to 10. In Sec. 11, recommendations on which products to use for different purposes are given.

Note that this document does not discuss how the products were made, the pipelines, or the different calibration schemes. A good starting point for the interested astronomer is the [PACS overview page](#), and the entry documents to read are the Quick-Start Guides (QSG) for [photometry](#) and [spectroscopy](#). The [PACS Handbook](#) provides more explanation of the pipelines, the products, the calibration, and the instruments themselves. The PACS Data Reduction Guides (PDRG) for [photometry](#) and [spectroscopy](#) should be consulted if you wish to reduce data or to understand the various mapping and cube-creating tasks.

2 PACS products in the HSA

The bulk of the PACS products present in the HSA are the result of the processing of the telemetry data with a set of standard pipelines, differentiated by observing mode, coded in the Herschel Interactive Processing Environment (HIPE). Those products are also referred to as Standard Product Generation (SPG) output. The observation data are described in Secs 3 (all pipeline products) and 4 (the SBPs). Also included in an HSA download is the calibration ‘tree’ (Sec. 5), the auxiliary data (Sec. 6), and the quality report (Sec. 7).

Additional products are also served by the HSA or can be obtained directly from various ESA websites.

- User-Provided Data Products (UPDPs) are products delivered by external users, 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 Sec. 9.
- Ancillary Data Products (ADPs) are products with complementary or historical information relevant to PACS, from a scientific or engineering perspective. Some of these are available in the PACS calibration context, but for convenience some are also provided as

ADPs. The ADPs are further described in Sec. 10.

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 PACS pipeline products (SPG)

In an *Observation context*, i.e. an observation downloaded from the HSA, the entirety of the data for any observation can be found: the raw data (Level 0), the reduced data (Levels 0.5 to 3), the calibration tree used to reduce the data by the SPG pipelines, auxiliary data, quality reports and – if viewing via HIPE – an observation summary. Each of these levels – as well as the entire observation – is a *context*: a product that links together other products (think of it as an inventory or directory). A schematic giving an overview of the products held in an Observation context is given in Fig. 1.

An Observation context downloaded from the HSA unpacks with a directory structure that reflects the pipeline levels and the product types, with FITS file names that reflect the product type and sequence.

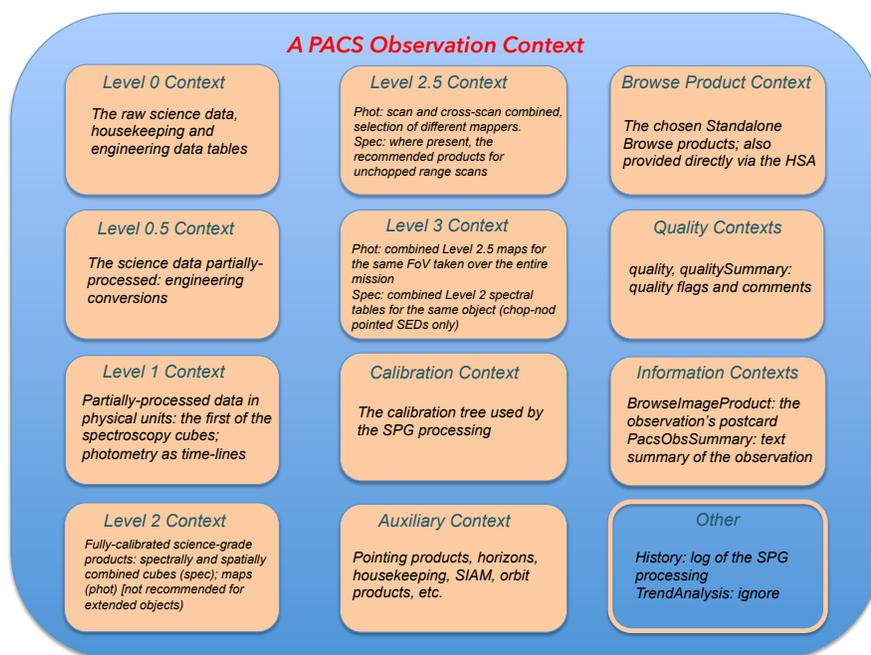


Figure 1: The structure of a PACS observation context

Each PACS Observation context is the outcome of the Standard Product Generation (SPG) pipeline(s), run in bulk with a given version of the Herschel Common Software System (HCSS). The SPG version, present in the FITS keyword of any of the products in the observation, indicates the HCSS version of the reprocessing. A number of SPG pipelines were used to process

PACS photometer and spectrometer data, these being distinguished on observing mode (AOT: astronomers observation template). The SPG scripts are available in HIPE ('Pipelines' menu) and are explained in the [PACS Handbook](#).

For PACS, the vast majority of the products served in the HSA were processed with version 14.2.0 of HIPE. A subset of observations were processed with 14.2.1 and 14.2.2 to fix oversights in 14.2.0.

PACS data were processed by the pipelines in increasing levels of processing, Level 0 being the lowest level products available to archive users, Level 3 being the highest. Science data can be found at Level 2 and above.

3.1 Photometer products

A summary of what is contained in the contexts of a PACS photometer observation:

- **Level 0:** Raw data, formatted from the raw telemetry by an external pre-processing stage.
- **Level 0.5:** Engineering conversions, pointing information computed, data organised in blocks and internal calibration block removed. Level 0.5 data are the uncalibrated, uncorrected timelines.
- **Level 1 :** Data taken during telescope slews and from bad detector pixels are masked out, as are cross-talk and saturation. Flatfielding and non-linearity corrections applied. For SSOs the coordinate system is set so the object is in a fixed position on the sky at all times. Level 1 data are still timelines but are flux calibrated (units of Jy).
- **Level 2:** The timeline detector data from Level 1 are projected on to a sky grid: one red camera and one blue camera map for each observation (noting that the blue camera was used for the blue band and green band observations). Data glitches are masked out, the source masked, timelines cleaned with the *highPass filtering* (HPF) task and the data projected using the *photProject* (PP) task. Level 2 data are maps in units of Jy/(map pixel).
- **Level 2.5:** For observations with a scan AOT and cross-scan AOT, the Level 2 maps are combined into a red and a blue HPF+PP map. In addition, the *JScanam* and *Unimap* tasks are run on the scan and cross-scan Level 1 data to produce Level 2.5 maps directly. Level 2.5 data are maps in units of Jy/(map pixel). The *JScanam* and *Unimap* maps are suitable for use on point and extended sources, but the *photProject* maps only for point sources.
- **Level 3:** For observations that are otherwise unrelated (e.g. were not part of the same programme) but overlap on the sky and have a compatible AOT, a mosaic map is created from all the available observations. These maps are superior to Level 2.5 in terms of sensitivity. What combination of blue, green, and red maps are present depends on the common bands in the observations that were combined.
- **Calibration:** The calibration files used by the SPG pipeline. This directory is located at the level of the *obsid* directory, and organised as subdirectories with calibration product names.
- **QualitySummary:** The *qualitySummary* contains flags and comments concerning issues with the observation. Unfortunately it is difficult to read this from the FITS file in this directory, but a human-readable version can be found in the HSA search results tab ('QCR').

- **BrowseProduct:** Contains the standalone browse products (SBPs), which are the Level 2.5 JScanam maps except for observations with only one scan direction, where they are the Level 2 maps.
- **BrowseImageProduct:** Contains the postcard that can be found on the HSA search results page, as a jpeg wrapped in a FITS file; however, it is easier to look at the jpeg file one directory up from here.

The folder structure of the unpacked observation downloaded from the HSA is described in Table 1.

Table 1: High-level overview of an unpacked photometry Observation context; filename patterns are given in Table 5

Folder	Sub-folder	Description
level0	HPENG, HPENGHK, HPPDMC[B R], HPPHK HPPAVG[B R]	Housekeeping and engineering data used in pipeline processing Raw science data
level0_5	HPPAVG[B R]	Partially-processed science data
level1	HPPAVG[B R]	Slightly more processed science data
level 2	HPPPMAP[B R]	Maps from this observation; final level for chop-nod observations and the scan-map mode with only a scan observation
level2_5	HPPHPFMAP[B R] HPPJSMAP[B R] HPPUNIMAP[B R]	Maps from the combined scan and cross-scan observation, using the high-pass filter and photProject tasks Ditto, using the JScanam task Ditto, using the Unimap task
level3	HPPJSMAP[B R] HPPUNIMAP[B R]	Maps from all observations that have a sky overlap with this observation, using the JScanam task Ditto, using the Unimap task
browseImageProduct	–	The postcard wrapped in a FITS file; <i>ignore</i> , the postcard jpeg file is also provided (one level up from here)
browseProduct	[blue red]_Jscanam_map [blue red]_projected_map	The Standalone Browse Products taken from Level 2.5 Where Level 2.5 is not present, the SBPs taken from Level 2
quality, qualitySummary	– –	The quality control report history, the final report; <i>ignore</i> , best read from the HSA instead

For more on the observing modes and map-making tasks, see Sec. 3.5, the [QSG: photometry](#), and the [PACS Handbook](#). The notation [B|R] means blue and red camera; HPP = Herschel Pacs Photometry

The HPPxxx folders contain the FITS files that are the data described in Table 1. The filename patterns for the FITS files contained in Level 2 and above can be found in App. 12.1.

A sketch of how the pipeline worked is shown in Fig. 2. This can help understand how the maps at Level 2, 2.5, and 3 related to each other.

Note that not every observation will have every level, although most do have a Level 2.5, as most observers did request a scan *and* cross-scan observation; Level 3 exists only if there are multiple observations that overlap with the sky field of the observation in question, and had a compatible observing mode. If there is only a red map in Level 3, this is because the blue camera of the combined observations were not done with the same filter (a choice of blue *or* green filter had to be made for all photometry observations).

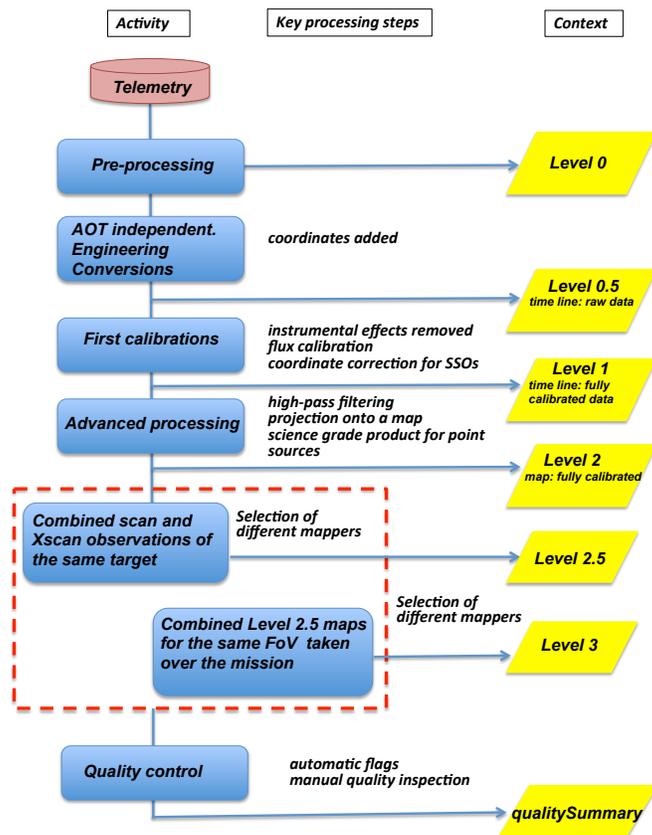


Figure 2: A sketch of the photometer pipeline

In addition to the folders listed in Table 1, the directories ‘auxiliary’ and ‘calibration’ can be found. These contain subdirectories in where the FITS files containing auxiliary and calibration data can be found: these are described in Secs 5 and 6.

3.1.1 Details on the PACS maps

The data contained in the various FITS file extensions of the PACS maps are tabulated in App. 12.1. The image, coverage, and error/stDev extensions contain the data useful for science analysis. For details on how these data were created by the pipeline, turn to the [PACS Handbook](#) or the [PACS Data Reduction Guide \(phot\)](#).

Pixel sizes for all maps are 3.2'' for blue/green parallel mode AOTs and 1.6'' for the blue/green prime mode, and 3.2'' for all red band data. The three mappers used on scan map observations were: HPF+ PP, which are HIPE-unique tasks; JScanam ([Graciá-Carpio, Wetzstein, Roussel, 2015](#)), which is the HIPE implementation of the IDL mapmaker [Scanamorphos](#) (Roussel, 2013);

and the code [Unimap](#) (Piazzo et al., 2015), which is spawned from HIPE. The JScanam and Unimap maps are suitable for use on any type of source, the HPF+PP maps are suitable only for point sources.

3.2 Spectrometer products

A summary of what is contained in the contexts of a PACS spectrometer observation:

- **Level 0:** Raw data, formatted from the raw telemetry by an external pre-processing stage.
- **Level 0.5:** Engineering conversions, timing and pointing information computed, bad-data masking, data organised in blocks. For SSOs the coordinate system is set so the object is in a fixed position on the sky at all times. Level 0.5 data are signal timelines, uncalibrated but with the first spectral and spatial conversions done.
- **Level 1:** Glitch masking performed, and the data are organised into the first cube of the pipeline, with dimensions $5 \times 5 \times [\text{nr. readouts}]$. The signal of chop-nod AOTs are dark and background subtracted and for unchopped AOTs are dark subtracted. Level 1 data are organised as timelines and are calibrated: Jy for unchopped AOTs and ‘telescopes’ for chop-nod AOTs.
- **Level 2:** Data are spectrally flatfielded and a second de-glitching performed. A regular wavelength grid is created for each cube and the data arrays (flux etc.) resampled along this grid, to create ‘native’ (aka ‘rebinned’) cubes, and stddev array is computed. For unchopped line-scans the background is then subtracted. For pointed and tiling observations, interpolated cubes are created. For mapping observations the cubes provided depend on the AOT, and this is explained later in this guide: the choices are drizzled, projected, and interpolated (the decision is made independently for the red and blue camera; the type of cube provided may not be the same for the two). Rebinned cube tables are created from the rebinned cubes and point-source tables created for all pointed AOTs. Level 2 data have units of Jy/pixel, where the ‘pixel’ refers to the spaxel in the cube, which is a $9.4''$ spaxel for rebinned cubes, and a smaller ($0.5''$ – $3''$) for all other cubes.
- **Level 2.5:** For unchopped range-scan mode on-source observations that have an associated off-source observation, the two observations are each reduced to Level 2. Extended processing then subtracts the off-source data from the on-source data to produce the same range of background subtracted products, which are placed in the Level 2.5 of the on-source observation. If the observer did not request an off-source observation, the final level is Level 2. To know which off-source observations correspond to the on-source observations, consult the comments in the `qualitySummary` in the `ObservationContext`, or consult the [list](#) on the [data products overview page](#).
- **Level 3:** This level is provided for pointed chop-nod observations which requested the full SED of a source, obtained via two, sometimes three separate observations. The red and blue point-source tables for all observations are concatenated into a single table. Consult the [list](#) on the [data products overview page](#) to know which obsids these are.
- **Calibration:** The calibration files used by the SPG pipeline. This directory is located at the level of the `obsid` directory, and organised as subdirectories with calibration product

names.

- **QualitySummary:** The qualitySummary can be found for every standard observation (but not for all calibration observations). It contains flags and comments concerning issues with the observation. Unfortunately it is difficult to access this from the FITS file in this directory, but a human-readable version can be found on the HSA search results tab.
- **BrowseProduct:** Contains the standalone browse products (SBPs: see later).
- **BrowseImageProduct:** The postcard that can be found on the HSA search results page can also be found here, a jpeg wrapped in a FITS file: it is better to look at the jpeg itself, which is provided one directory up from here.

The folder structure of an unpacked observation downloaded from the HSA is described in Table 2. The HPSxxx folders contain the FITS files that are the data described in the table. The filename patterns for the FITS files contained in Level 2 and above can be found in App. 12.2. The data contained in the various FITS file extensions of the PACS maps are also outlined there. A sketch of how the pipeline worked is shown in Fig. 3. This can help understand how the products at Level 2, 2.5, and 3 related to each other.

In addition to the folders listed in Table 2, the directories ‘auxiliary’ and ‘calibration’ can be found. These contain subdirectories in where the FITS files containing auxiliary and calibration data can be found: these are described in Secs 5 and 6.

3.2.1 Details on the cubes

Several types of PACS cubes are produced by the pipeline; Levels 2 and above are where the science-ready products can be found. For details on their science use, see Sec. 11. Some examples of the different cubes are shown in Fig. 4.

- **Rebinned cubes** (HPS3DR[B|R]): are the first science-use cubes produced by the pipeline, and are found at Level 2 and 2.5 for all observing modes. They have the native footprint of the PACS IFU, which is a 5×5 slightly irregular grid with 9.4"-sized spaxels (Fig. 5). Because of the irregularity of this grid, the sky coordinates are not encoded in the WCS (instead the spaxel indices are, which can make it *appear* that the footprint is regular when read in cube viewing software), and it may be difficult to view these cubes in software other than HIPE. It is for this reason that the rebinned cube spectrum table is also provided in an observation (Sec. 3.2.2).

The spaxel size of the rebinned cubes is not small enough to spatially sample the beam well (with a beam FWHM of 9"–13", these cubes do not even achieve a Nyquist resolution). This has the consequence that these observations are considered to be *undersampled*. These are the prime recommended cubes for science measurements of point and point-like sources.

- **Interpolated cubes** are mosaic cubes created by the pipeline task *specInterpolate*. This task resamples the spatial grids of mapping set of rebinned cubes, using Delaunay triangulation to find the best output spatial grid. The datasets from the input cubes are then interpolated onto the output grid. These cubes have a regular spatial grid which is encoded in sky coordinates in its WCS.

Table 2: High-level overview of an unpacked spectroscopy Observation context filename patterns are given in Table 7

Folder	Sub-folder	Description
level0	HPENG, HPENGHK, HPSDMC[B R], HPPHK HPSRAW[B R] HPSFIT[B R]	Housekeeping and engineering data used in pipeline processing Raw science data On-board fitted raw data
level0_5	HPSDMC[B R] HPSFIT[B R]	Dec-Mec data used in pipeline processing Partially-processed science data
level1	HPSFIT[B R] HPS3D[B R]	Slightly more processed science data The HPSFIT[B R] data organised as a cube
level 2	HPS3D[B R] HPS3DR[B R] HPS3DI[B R] HPS3DEQI[B R] HPS3DP[B R] HPS3DEQP[B R] HPS3DD[B R] HPS3DEQD[B R] HPSSPEC[B R] HPSTBR[B R]	Level 1 cubes, flatfielded The HPS3D cubes, spectrally rebinned Interpolated cubes: spatially resampled+mosaicked HPS3DRs Ditto, but with an equidistant spectral grid Projected cubes: spatially resampled+mosaicked HPS3DRs Ditto, but with an equidistant spectral grid Drizzled cubes: spatially resampled+mosaicked HPS3DRs Ditto, but with an equidistant spectral grid Table containing spectra of the central spaxel and 2 or 3 point-source corrected spectra Tabulated version of the HPS3DR[B R] data
level2_5	see above	same products as Level 2, but background subtracted (with 'BS' near end of filename), for the unchopped range-scan mode
level3	HPSSPEC	The spectrum tables taken from the Level 2 for all chop-nod SED observations taken of the same target
browseImageProduct	–	The postcard wrapped in a FITS file; <i>ignore</i> , the postcard jpg file is also provided (one level up from here)
browseProduct		The Standalone Browse Products, taken from Level 2, 2.5, 3
quality, qualitySummary	– –	The quality control report history, the final report; <i>ignore</i> , best read from the HSA instead

More on the observing modes can be found in Sec. 3.5, the [QSG: spectroscopy](#) and the [PACS Handbook](#) for more on observing modes and the product types listed here

The notation [B|R] means blue and red camera; HPS = Herschel Pacs Spectroscopy. 3D = cube

Interpolated cubes are provided for tiling and other spatially undersampled mapping observations, and for pointed observations. In all cases, the spatial pixels of the interpolated cubes are 3".

These are the prime recommended cubes for science measurements of extended sources in undersampled observations (pointed or tiling).

- **Projected cubes** HPS3DP[B|R]: are mosaic cubes created by the pipeline task *specProject*. This task creates an output spatial grid from the grids of the mapping set of rebinned cubes; the datasets from the rebinned cubes are then projected onto this output grid. These cubes have a regular spatial grid which is encoded in sky coordinates in its WCS.

Projected cubes are provided for Nyquist and oversampled mapping observations. If a drizzled cube is also created for that observation, then the projected cube has spatial pixels

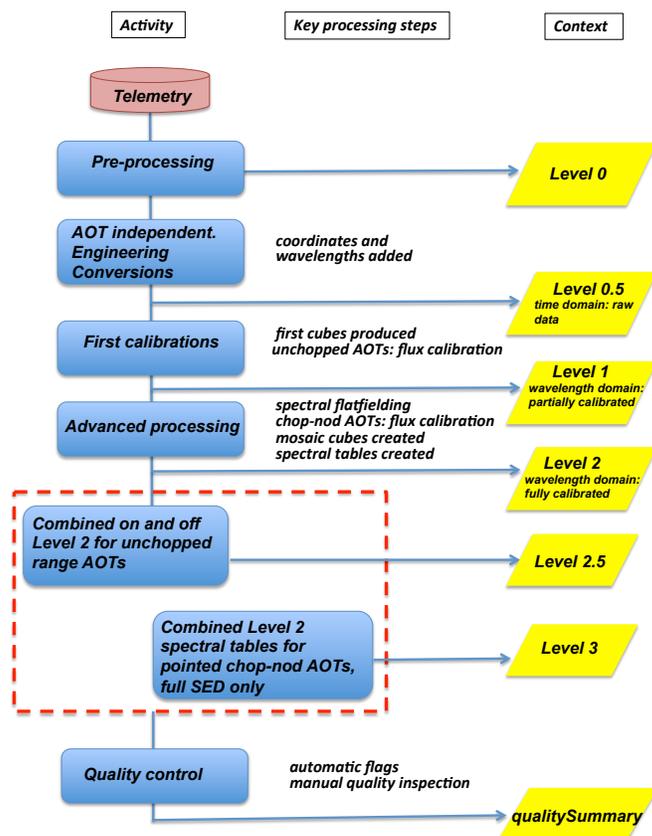


Figure 3: A sketch of the spectrometer pipeline

with the same size as for the drizzled cube, otherwise they are $3''$.

Projected cubes are also provided for tiling observations, with spatial pixels of $1.5''$, and pointed observations, with spatial pixels of $0.5''$. Projected cubes are not the prime recommendation for science measurements for these types of observations mainly because their small spatial pixel size results in a very large number of spectra in the cubes, which can be awkward to handle. The interpolated cubes are generally easier to deal with for tiling observations and for pointed observations of extended sources.

- **Drizzled cubes** (HPS3DD[B|R]): are mosaic cubes created by the pipeline task *drizzle*. These cubes also have a regular spatial grid which is encoded in sky coordinates in its WCS. Drizzle creates the output grid from the grids of the mapping set of input cubes, and the spectral data are ‘drizzled’ onto the output grid.

The size of the spatial pixels of the drizzled cubes is optimised to the wavelength; consequently these cubes are only provided for Nyquist and oversampled mapping line-scan

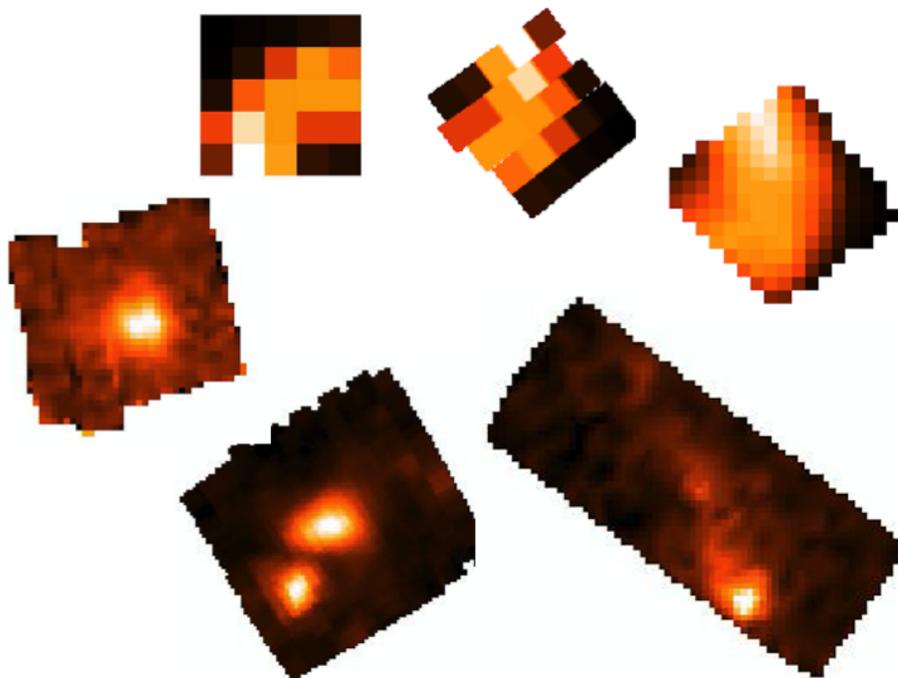


Figure 4: Random examples of PACS cubes. Images are integrated emission line fluxes. Clockwise from from top left: A **pointed observation**: rebinned cube (9.4'' spaxels, no WCS, orientation is along the instrumental axes), same observation as a projected cube (0.5'' spatial pixels, you can see the shape of the IFU's footprint), next as an interpolated cube (3'' spatial pixels); **Mapping observations**, an interpolated cube from a tiling observation (3'' spatial pixels), a projected cube from a Nyquist sampling observation (3'' spatial pixels), and a drizzled cube from an oversampled observation ($\leq 3''$ spatial pixels).

observations, where the spectral coverage is short. The size of the spatial pixels for each drizzled cube (i.e. for each requested spectral line region) in the observation is different. It is possible to create new drizzled (or any other mosaic) cubes using a script in HIPE (Scripts→PACS useful scripts→Spectroscopy: Create mosaic cubes with any spaxel size).

Where a drizzled and a projected cube is provided, it is up to the astronomer to decide which use: they are both equally well calibrated, so the differences lie in the sophistication of the mosaic task and in which 'looks better' to the astronomer.

All the pipeline tasks that create the mosaic cubes are explained in the [PACS Data Reduction Guide \(spec\)](#) (chps 7–9). To know whether any PACS spectroscopy observation is pointed or one of the mapping modes (Nyquist, oversampled, undersampled, tiling; or pointed) see Sec. 3.5. Note that the decision about whether an observation is one or another mapping mode is made independently for each camera, and this often resulted in different types of cubes being provided for the red and the blue camera of the same observation.

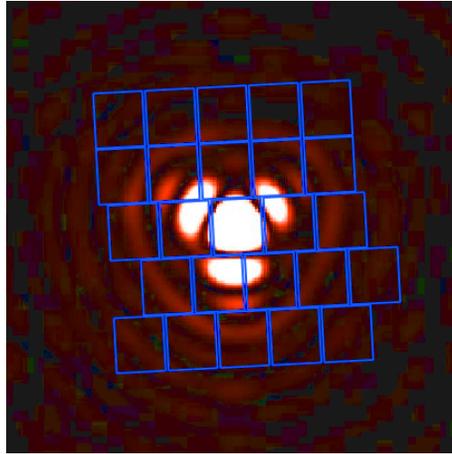


Figure 5: The PACS IFU footprint plotted over the blue spectroscopy beam

3.2.2 Details on the spectroscopy tables

Two types of tables are provided for PACS spectroscopy observations.

- **Point-source spectrum tables** (HPSSPEC[B|R]): are provided for pointed observations only (and regardless of the type of target that was observed). The organisation of these data in the spectrum tables is shown in Table 3. The spectra ‘c1’, ‘c129’, and ‘c9’ are point-source calibrated spectra produced by the pipeline task *extractCentralSpectrum*, which is explained in App. 12.4; note that c129 is not provided for the unchopped observations. For units given as Jy/pixel, the ‘pixel’ is a 9.4'' spaxel. At Level 3 the product is called HPSSPEC and can be found only in the chop-nod pointed observations where a full SED of the target (obtained via 2 or 3 observations) was requested.
- **Rebinned cube tables** (HPSTBR[B|R]): are provided for all observations. They contain the data of the rebinned cubes (HPS3DR[B|R]) in a tabular format. The organisation of the data is shown in Table 4. For units given as Jy/pixel, the ‘pixel’ is a 9.4'' spaxel. The data were added to the table such that a complete spectrum (wavelength, flux, flux error, ra, dec) from one spaxel, one raster position, are given, then the entries iterate on spaxel coordinate and then raster coordinate. Hence, for a spectrum from a mapping observation with 10 wavelength points you will find:
 - row 0–9: data for raster (line 1, column 1) for spaxel (index 0, row 0, column 0)
 - row 10–19: data for raster (line 1, column 1) for spaxel (index 5, row 0, column 1)
 - row 20–29: data for raster (line 1, column 1) for spaxel (index 10, row 0, column 2)
 - row 30–39, 40–49: ditto for spaxel indices (15, 20) and spaxel columns (3, 4)
 - repeat, iterating until all spaxel rows (0...4) for all spaxels columns (0...4) have been done
 - repeating the entire set for raster (line 1, column 2); and so on until the end of the raster sequence

Table 3: The organisation of the data in the spectrum table. See App. 12.4 for the definitions of c1,c129,c9

Segment number	Wave	Band	Flux	Error	Flux	Error	Flux	Error	Flux	Error
To distinguish data from different slices or observations	μm	(filter)	central spaxel Jy/pixel	spaxel Jy/pixel	c1 Jy	Jy	c129 Jy	Jy	c9 Jy	Jy

Table 4: The organisation of the data in the rebinned cube table

Raster line	Raster col.	Band	Spaxel index	Spaxel row	Spaxel col.	RA	Dec	Wave	Flux	Error
0, 0 for pointed 1,2,3... both for mapping		(filter)	0...24	0...4	0...4	deg		μm	Jy/pixel	

3.2.3 The wavelength grid of PACS cubes and tables

The wavelength grid of all PACS Level 1–2.5 cubes (and all tables created from the cubes) are regular *but non-equidistant*. Since the spectral resolution of the PACS spectrometer varies with wavelength, it was decided that the size of the wavelength bins should also, such that the effective spectral sampling is the same across the entire spectral range. This is most obvious when inspecting cubes of wide spectral range, e.g. the SEDs. This spectral grid is demonstrated in the [PACS Data Reduction Guide \(spec\)](#) (sec. 7.2). The spectral grid is provided as an extension in the cube FITS file (see Table 9).

One disadvantage of this spectral grid is that it cannot be encoded as a digit in the WCS keyword ‘cdelt3’, as the dispersion varies across the range. However, the FITS file extension ‘wcs-tab’ is a lookup table for the spectral grid, and this is a WCS-compliant way to deal with these types of spectral products. Nonetheless, it was decided to also give a subset of PACS spectral cubes an equidistant spectral grid, and provide them as SBPs (Sec. 4); external cube-viewing software can deal with these ‘equidistant cubes’ more easily.

3.3 Slicing in the pipeline

PACS spectroscopy products can be large, and to improve the performance of the pipeline, the data were sliced into ‘blocks’ split by nod position, chop position, raster position, and the separate spectral ranges. These blocks were held together in a context, and reduced together through the pipeline. The photometry pipeline also did this ‘slicing’, although it was less necessary for these data and there was only ever one slice (i.e. the entire dataset) held in any context as the data were pipeline processed.

For the archive user of PACS data, the only reason to be aware of this is that the pipeline products from an observation downloaded from the HSA are consequently organised within their directories as separate ‘slices’. For photometry the slice number in the FITS files is always ‘00’ (=slice number 1, the only slice). For spectroscopy there are more FITS file slices:

- Level 2 and 2.5 rebinned cubes (HPS3DR[B|R]) are sliced on raster position and wavelength, hence for a 3x3 raster with 2 wavelength regions, there will be 18 slices/cubes in

the observation, and therefore 18 FITS files in this directory

- Level 2 and 2.5 mosaic cubes (interpolated, projected, drizzled: HPS3D[IPD][B|R]) are sliced on wavelength only
- Level 2 and 2.5 rebinned cube spectrum tables (HPSTBR[B|R]) contain all raster positions in one cube, so are only sliced on wavelength
- Level 2 and 2.5 spectrum tables (HPSSPEC[B|R]) are sliced on wavelength range (they do not need to be sliced on raster position as they are only provided for pointed observations)
- The Level 3 spectrum table (HPSSPEC) contains all the red and blue camera data for all obsids that were taken to cover the full SED (55–190 μm) of a target, hence only one table (one slice) is provided

App. 12.2 shows what the FITS filename look like, and where the slice numbering comes in.

3.4 Missing products

In cases where an observation partially failed, only some of the data of the observation will be provided. If the observation could not process to the end of the pipeline it will be classified as failed (unless it is a non-standard calibration observation). If data from one camera are missing/corrupted, but the other camera was fine, then only these data are provided. Any instrument anomalies that led to this will have been noted in the quality control report (Sec. 7).

Additionally for spectroscopy, any data that falls outside of the band limits, in the red leak region, or in the blue uncalibrated region, are not provided, *even* if the observer specifically requested them. The red leak and blue uncalibrated regions are provided instead as HPDPs (Sec. 9). If all of the wavelength range(s) in one of the cameras (red, blue) are ‘out of band’, then that camera will not have processed to the final level of the pipeline – for these cases a comment will have been added to the quality report.

The spectral ranges that are *in band* are: R1=102–190 μm ; B2A=55–73 μm ; B3A=55–70 μm ; B2A=70–95 μm .

3.5 How (and why) to know the observing mode

The observing mode of any PACS observation determined what type of images or cubes were created by the photometry and spectroscopy pipelines. For **photometry**, most observations were scan mapping and the range of maps provided is the same in most cases. The only thing the archive user may want to know is: whether the observation is one of a scan+cross-scan pair; and whether the observation is parallel with SPIRE. For **spectroscopy**, a greater range of AOTs was offered, leading to a greater variation in the type of cubes and tables provided (e.g. as listed in Sec. 3.2.1). *Noting that calibration and data uncertainties, and the science-usability of the various cubes and tables created by the pipeline, depend on the source and the AOT*, it is good idea to know observing mode your PACS spectroscopy data were taken with.

To know the AOT of an observation, it is necessary to look at the keywords in the FITS file (the cubes or images from that observation that you want to start working on). All keywords can be found in the [PACS Handbook](#), but those necessary to decode the AOT are also given in App. 12.3.

3.5.1 PACS spectroscopy mapping modes

The pointing modes of spectroscopy are especially important to know because the types of cubes provided are different for each mode, and whether the beam is undersampled or well sampled depends on the pointing/mapping mode. Why is the spatial sampling important? For well sampled observations, the obtained spatial sampling allows for full reconstruction of the source morphology up to the spatial resolution of the beam, but for undersampled observations this is not the case.

In Sec. 3.2.1, the names of the cubes provided for the different modes are listed, and in Table 11 the FITS file keywords that can be used to decode the observing mode are given. The mapping modes were designed by the observer by choosing the raster step sizes and number of steps in the two orthogonal directions, and there were no limitations on the choices (other than observing time). However, to allow the pipeline to determine which types of cubes to create for any single observation, four classes of mapping mode were defined: oversampled, Nyquist sampled, tiling, and undersampled. The limits were defined as a minimum number of raster steps with a maximum step size. The definition depends on the camera: since the beam is larger in the red than in the blue, the raster in the red can be more sparse and still achieve the same relative beam sampling as in blue.

- *Oversampled mapping* observations were those with a least 2×2 steps with step sizes of $\leq 4.5''$ (red), or 3×3 steps with step sizes of $\leq 3''$ (blue).
- *Nyquist-sampling mapping* observations were those with least 2×2 steps with step sizes of $\leq 24''$ (red), or 3×3 steps with step sizes of $\leq 16''$ (blue).
- *Tiling* observations are those with larger steps sizes than for Nyquist-sampling (and any number of steps).
- *Undersampled* observations are any mapping observations that do not have the correct number of steps or step sizes to fit into the definitions give above. Note that if the observer's spectral region of interest was in the red and they requested 2×2 steps, then data in the blue for that observation will *always* be considered undersampled, as there are too few steps.
- *Pointed* observations are undersampled.

Note that it is possible to create any type of cube with any reasonable spaxel size working directly from an observation gotten from the HSA using a script in HIPE: Scripts→PACS useful scripts→Spectroscopy: Create mosaic cubes with any spaxel size.

4 PACS Standalone Browse Products (SBPs)

The science-quality products that the pipelines produce are found in Level 2, 2.5, 3. PACS have also created products that can be downloaded as a tarball of FITS files from the HSA directly, to be read into HIPE or into any other software: these are called the Standalone Browse Products. For photometry these are simply the most highly recommended maps for the different observing modes. For spectroscopy they are slightly modified version of one of the set of Level 2/2.5 cubes,

and an additional set of tables. The products can be found in the ‘browseProduct’ directory of an unpacked HSA tarball. Their filename patterns are given in Tables 5 and 8.

The term ‘standalone browse’ means that the products have a format that allows them to be loaded into other software fairly easily and are a good example of the data the observation has produced. For photometry the standalone products are also science products that can be used for any type of target. For spectroscopy they are science-level cubes but modified in one important way: in order to make the cubes easier to read into other software it was necessary to modify the wavelength grid to make it equidistant. This necessarily changed the spectral data slightly.

4.1 Photometer

The Level 2.5 JScanam maps are the SBPs, and they are science-ready for point sources and extended emission. For the few observations where only one scanning direction was taken, the HPF+PP maps are provided instead. These are science-ready for point sources, but for extended sources it may be necessary to re-pipeline the data (to increase the size of the high-pass filter, so as to not filter out real source emission). In this case it is suggested the user first checks for the presence of a Level 3 or an HPDP.

The filenames for the SBPs can be found in Table 5.

Note that the Unimap maps provided at Level 2.5 are just as science-ready as the JScanam maps: users are advised to inspect both before starting to work with their data.

Level 3 maps are not provided as SBPs because they are not uniformly present for all observations, and because the quality control performed at the HSC was done on the Level 2.5/2, not the Level 3. However, if any Level 3 maps are present, these are generally preferred (because of their superior sensitivity) *unless* there are any obvious artefacts in the maps (in these few cases, the artefact is probably present in one of the observations that were combined to create the Level 3).

4.2 Spectrometer

The spectroscopy SBPs are ‘equidistant cubes’ taken from Level 2 and, if present, Level 2.5. Where both Level 2 and 2.5 are present (for the unchopped range-scan observing mode only), the Level 2.5 are the background-subtracted data and have a ‘BS’ in the directory and FITS file names. Only one type of cube is provided, depending on the AOT. All spectral tables from Level 2, 2.5, and 3 are also provided.

The difference between the equidistant and the standard cubes is in the spectral grid. The standard cubes have a non-equidistant wavelength grid (Sec. 3.2.3), while the SBP cubes have an equidistant grid (hence the ‘EQ’ in the filename). These equidistant cubes were the output of a pipeline task that takes a standard Level 2/2.5 cube and resamples its spectral grid to become regular and *evenly-spaced*, and then interpolates the various 3d arrays in the standard cube onto this evenly-spaced grid. By choosing small bin sizes for the equidistant spectral grid – a fraction 0.35 of the smallest wavelength bin in the input cube – the ‘new’ spectra follow the ‘old’ spectra closely (to the eye there is very little difference). However, while the appearance of the spectra are not changed, it should be noted that the spectral sampling in the equidistant cubes is far higher than the spectral resolution and original spectral sampling warrant. Do not be confused

by this. Note also that for cubes with a full SED spectral coverage, the size of the FITS files is larger than for the standard cubes (one example: from 16.7 Mb to 47.7 Mb).

If a user wishes to create their own equidistant cubes with different bin sizes, there is a HIPE script to show how to do this: Scripts→PACS useful scripts→Spectroscopy: Re-create the standalone browse products.

The filenames for the SBPs can be found in Table 8. One type of cube is provided from Level 2, and the same type from Level 2.5 (where present). Which cube is provided depends on the AOT:

- For Nyquist and oversampled mapping line-scan modes: the drizzled cubes (HPS3DEQD[R|B], or HPS3DEQDBS[R|B] for the Level 2.5 version)
- For Nyquist and oversampled mapping range-scan modes: the projected cubes (HPS3DEQP[R|B] or HPS3DEQPBS[R|B] for the Level 2.5 version)
- For all other modes (pointed and undersampled mapping, line and range-scan): the interpolated cubes (HPS3DEQI[R|B] or HPS3DEQIBS[R|B] for the Level 2.5 version)

Note that the mapping mode is computed for each camera independently, and hence it is possible that an observation will be oversampled in the red but undersampled in the blue, and the red and blue SBP cubes will not be of the same type: see Sec. 3.5.1.

All the spectrum tables that are present in the upper pipeline levels are also provided as SBPs (these have a standard spectral grid).

5 PACS calibration products

Each PACS Observation context downloaded from the HSA also contains the calibration tree that was used to reduce the data, and some auxiliary products. The entire calibration tree is provided in the download, as separate FITS files in the ‘photometry’, ‘common’, and ‘spectroscopy’ folders. The calibration tree can also be downloaded separately via HIPE (this is explained in the [PACS Data Reduction Guide \(spec\)](#)), where it is placed into a directory on disc (.hcss/data/pcal-community/) and consists of individual FITS files.

The final SPG processing run at the HSC and placed in the HSA used calibration tree PACS_CAL_77_0. The final calibration tree update was PACS_CAL_78_0, however the only difference is with one photometry calibration file and this had no impact on the SPG processing. The updated calibration file is ‘apertureCorrection’, which was given new aperture correction entries applicable for additional scan speeds. To get hold of this final aperture correction calibration file, it will be necessary download the calibration tree via HIPE and located that particular FITS file, or look for that particular file on the [HSC web-page](#) where all calibration files are stored. Note that tables of aperture corrections (including the update) are also provided in the [PACS Handbook](#). Table 10 shows how to know the scan speed of a photometry observation.

The contents of the calibration trees are tabulated in the [PACS Handbook](#). On the [HSC web-page](#) with the calibration files, a complete history of calibration updates can also be found (this is a compilation of the information in the ‘release-note.html’ files on that page).

6 PACS 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 auxiliary products were required by the pipeline during the different levels of processing. Other than this, it is very unlikely anyone will need to work directly with any auxiliary product. In the interactive pipeline scripts in HIPE, the names of the auxiliary and calibration products used with each pipeline task are indicated in the comments.

7 PACS quality report (QCR)

During the active phase of the Herschel mission, quality control (QC) was carried out incrementally at the HSC on all PACS observations, excluding calibration observations: checking for missing, corrupted, or otherwise incorrectly-recorded data and to see if it was necessary to reschedule the observation. In the post-operations phase, additional checks were carried out on all spectroscopy and photometry observations, now including calibration observations, to look for data artefacts (e.g. due to an inadequate performance of pipeline tasks, due to incorrect AOT programming, etc.) or other quality issues (e.g. saturation, missing data, bad pointing). Anything found is recorded in the QCR comments section. Note that this work is continuing through 2017. A few flags can also be seen in the QCR, but almost none are relevant. Where a flag indicated a real problem, there will be a comment about that problem.

The QCR can be best found and read on the HSA search results page. It is included in the observation download, but wrapped in a FITS file and not so easy to read.

8 PACS User Provided Data Products (UPDP)

UPDPs are provided by external users on a best-effort basis; the complete list of products hosted by the HSA will increase with time. The UPDP [main web page](#) provides a list of the currently available UPDPs. Each should have a release note with details about the delivered dataset.

9 PACS Highly Processed Data Products (HPDP)

Highly Processed Data Products (HPDPs) 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, provide alternative products that are better for a particular science analysis, or are complementary products which can be used to check on or inspect a certain aspect of the data.

The HPDPs are available at the [HSC legacy repository](#), and they will also be served from the HSA. Here we list and briefly describe the currently available PACS ones (mid-2017). Each sub-folder in the HPDP/PACS folder contains the products and a release note with details on the methods used to generate the products.

9.1 Photometer

Several of the photometry HPDPs are combinations of observations to produce superior maps. The PACS Point Source Catalogue is also provided as an HPDP.

- [JScanam large field maps](#). The main purpose of these HPDPs is the provision of higher-quality JScanam maps of very extended regions. These regions could not be covered by a single PACS observation and required several pointings. Combining these separate pointings into a single map covering the entire region could not be done by the SPG, nor could the extra work required to match the background fluxes in the overlap regions, and to account for the higher noise at the map edges when mosaicking the fields together. Examples of these kind of maps are those of the Milky Way, the Orion star forming region and the Large and Small Magellanic Clouds. The MCs are a special case because they were not observed with the standard scan+cross-scan mode, and hence JScanam maps were not even produced by the SPG pipeline.
- [Unimap extra maps](#). This HPDP has a similar goal as the JScanam large fields, but here Unimap maps will be produced. The fields include the North and South Galactic Poles, Bootes-Spitzer field, the MCs and the Bridge Region, L 1521, Draco cloud, Video-XMM fields, and a few others where the SPG pipeline did not produce Level 2.5 maps.
- [PACS Point Source Catalogue](#). The PACS PSC contains more than half a million entries in the three PACS bands. The catalogue consists of several tables provided as compressed CSV format files: one PSC table for each band; a list of slightly extended sources (HPESL); and a rejected source list (HPRSL).

9.2 Spectrometer

The spectroscopy HPDPs offer data that are not present in the SPG product, or provide data complementary to the SPG-processed observations. Currently only one HPDP is provided.

- [Red leak spectra](#). PACS Spectrometer observations with wavelengths longward of $190\ \mu\text{m}$ were not processed by the SPG pipeline, as these data are affected by order leakage (this is explained fully in the [PACS Handbook](#)). These data were instead processed with a non-standard calibration scheme for the chop-nod observations and the SPG calibration scheme for unchopped observations, in both cases with a dedicated relative spectral response function. The spectral cubes feature calibrated order 1 emission lines (i.e. those that originate in the red spectral range, rather than in the leaking range) in the $190\text{--}206\ \mu\text{m}$ range, while the continuum remains uncalibrated.
- **Blue uncalibrated range** (*not yet released*). The range between $51\ \mu\text{m}$ and $55\ \mu\text{m}$ cannot be calibrated, however there were data taken in this range (either because it is in the parallel

camera or because the observer specifically requested it). These data will be released without a flux calibration as an HPDP.

- **On-source and Off-source cubes.** In order to make it easier for users to inspect the off-source data from an observation, e.g. to check for the presence of contamination (line emission, mainly), all the unchopped line-scan and chop-nod observations will be processed to produce separate on-source and off-source cubes, and the postcard will show the field-averaged spectrum from the on-source and off-source together. For the unchopped range-scans it is not necessary to create separate cubes – the on-source and off-source are separate observations anyway – but postcards will be produced to show the field-average spectrum of the two observations together.
- **Pointing Offset Correction point-source spectra** (*not yet released*). For point sources observed with the chop-nod pointed mode, the point-source calibrated spectra produced by the Pointing Offset Correction (POC) script may be superior to those produced from the SPG pipeline, if there was a large pointing offset (i.e. the source is not in the centre) or a lot of pointing jitter during the observation. This script – which is an interactive pipeline script in HIPE – is currently being run on all observations of this mode, and the results – the spectra and the diagnostic data created by the pipeline – will be provided as an HPDP.

10 PACS Ancillary Data Products (ADP)

Ancillary Data Products (ADPs) are data (images, tables etc) generated in the course of the various phases of the Herschel mission which are not necessarily linked to a particular observation in the HSA. Some of the PACS ADPs are extracted from the products already available in the calibration tree attached to each observation. The ADPs can be obtained from the [HSC legacy repository](#).

The following lists the available PACS ADPs:

- **Models for calibration sources:** these ADPs include models for the planets, asteroids, and stellar calibrators used by PACS. The [calibrator models page](#) provides an entry point for accessing the available data. The models used by all the Herschel instrument can be found on these pages. The PACS spectroscopy calibrator models are also available from the [PACS ADP page](#). The same models are provided in both places, however on the PACS-specific page it is possible, via jython script (written for HIPE), to isolate immediately the PACS spectroscopy model spectra for each OD and for each calibration source observation.
- **PACS beams (PSF):** these are the beam profiles and beam maps for the photometer and spectrometer, the modelled and the observed.
- PACS photometer [filter transmission functions](#).
- **PACS On-board software:** compilation of Onboard Software (OSW) versions that were prepared for and uploaded into the Data Processing Unit (DPU) of the PACS instrument in the course of the operation phase of the mission. Top level documents such as the OSW user's manual, as well as the release notes, are provided.

- [PACS ICC health monitoring and trend analysis](#). This archive consists of a subset of PACS HouseKeeping information organised in dedicated trend and health monitoring plots per OD. Longer-term plots are also provided, as well as the daily memory dump event report that were generated throughout the mission.

11 Recommended PACS data products

Always check for any comments in the QCR (the quality report) before starting work with any PACS data.

11.1 Photometer

All PACS photometer products at Level 2 and above are science ready with the following caveats:

- HPF+PP maps should only be used for measurements of point-like emission. JScanam and Unimap maps can be used for point and extended sources.
- Level 2.5 maps should always be used in preference to Level 2 maps. Level 3 maps, if available, will have superior sensitivity but the maps should be checked for artefacts before use, as this level did not undergo quality control at the HSC.
- The maps have the unit of Jy/(map pixel) for the filter's reference wavelength and an input energy distribution which is constant in the flux per logarithmic frequency interval (flux per octave). The flux density with wavelength λ goes as $f_{\lambda} \propto \lambda^{-1}$.
- Aperture and colour corrections are tabulated in the [PACS Handbook](#), and aperture corrections are additionally available as a calibration file (see Sec. 5, and note that the corrections depend on scan speed, band, and observing mode).
- PACS maps are differential maps, where the absolute level is undefined as it is removed by the map-making process. Hence it is not a worry if the background level is negative. All measurements should be made with respect to the (source-free) background on the maps.

11.2 Spectrometer

The spectrometer products are numerous, and first some advice in navigating them may be useful:

- A range of cubes are provided at Levels 2 and 2.5, and which cube is the best to use depends on the AOT, hence you should first find the AOT of your observation (Sec. 3.5), and then read about how the different cubes and tables were created (Secs 3.2.2 and 3.2.1).
- Level 2.5 contains the background-subtracted version of the Level 2 for unchopped range-scan observations, and hence is the science-ready level for this AOT. If not present, then the observer did not request an off-source observation, and Level 2 should be used instead.
- For most *mapping* observations, two types of mosaic cube and the rebinned cubes are provided (see Sec. 3.2.1). Where more than one type of mosaic cube is provided, the

choice as to which to use is up to the astronomer (based on the information given here, in the [QSG: spectroscopy](#), and the [PACS Handbook](#)), since all are equally-well calibrated.

- For *pointed* observations, the rebinned plus the interpolated and projected mosaic cubes are provided. The former should be used for science measurements of point and point-like sources (using HIPE tasks to perform the necessary corrections), the latter two can be used for sources with extended emission, noting that between these two the interpolated cubes are usually easier to use and from them the source's morphology is easier to envisage.

If using HIPE, it is recommended to *also* do the science measurements for extended sources from the rebinned cubes (e.g. to fit emission lines), but since it will also be necessary to do an interpolation to view the results (e.g. to turn the emission line fits into flux maps), using the mosaic cubes for extended emission outside of HIPE is acceptable.

- The SBP cubes are science-ready, and they can be used in preference to the cubes at Level 2 and 2.5 after first reading Sec. 4 to learn how the SBPs were created.
- The rebinned cube tables are provided for convenience, and are their most likely use case is when external software cannot read the rebinned cubes themselves.
- The point source tables contain point-source calibrated spectra, which are valid for point sources located in the centre of the FoV: see App. 12.4 for more information.

All cubes and tables at Levels 2, 2.5, and 3 contain science-ready data, however there are limitations that apply to the various products, and additional corrections that are necessary or at least recommended:

- The calibration uncertainties, and the limitations on science measurements, depend on the AOT. This is documented in the [QSG: spectroscopy](#) and [PACS Handbook](#).
- The flux unit is Jy/pixel, where the pixel is the spatial pixel of the cube (no matter what its size). The spaxels of the rebinned cubes are 9.4", for the interpolated cubes it is 3", and for the projected and drizzled cubes the size can be found in the WCS.
- The fluxes of very extended sources (with a gradient of roughly no more than 20% over the FoV of the IFU footprint) are fully calibrated. For point, small, and extended+irregular/steep sources, extra flux corrections are necessary:
 - *Point-source corrections are necessary for point sources.* Tasks in HIPE are provided to do this, see the advice in the user note [Dealing with point sources](#). The task to use depends on where the source is in the FoV. One of these tasks is applied by the pipeline and provided in the Observation context as the point-source spectrum table (HPSSPEC), but *only* for pointed observations (and regardless of the type of target observed). However, these data are *only* valid if the source is in the central 3×3 spaxel box in the FoV of a rebinned cube. For larger offsets, the advice in the user note can be followed. See App. 12.4 for more detail on how these point-source spectra are computed.
 - *For slightly extended sources, semi-extended source corrections can be applied in HIPE.* The tasks compute the correction to the flux extracted from the central region of a rebinned cube. This is generally better than simply summing up the spectrum

in the FoV, but it does require as input a model of the source morphology. See the advice in the the note [Dealing with semi-extended sources](#).

- *For extended sources, extra corrections to account for the non-contiguous nature of the PACS IFU (which lead to an uneven illumination of the FoV) are recommended, although this is an advanced use-case. This is for pointed or mapping observations. See the advice in the user note [Dealing with extended sources](#).*
- Do not over-interpret the morphology of sources from undersampled observations: these data are not suitable for looking at structure at the limit of the spatial resolution, since the spatial *sampling* is poor.
- Do not over-interpret the profile of spectral lines without first considering that any point or point-like source that is not fully centred in a spaxel on the rebinned cubes will develop (i) line shifts and (ii) a skew. This is a consequence of the image slicer design for the PACS spectrometer. See the [PACS Handbook](#) for more information.

A decision tree, provided to guide the user through the various options when working with point, small, or extended sources, for all the AOTs of PACS spectroscopy, can be found on [HELL \(level 1\)](#) (specifically [here](#)). It is strongly recommended that the user of PACS spectroscopy reads this before starting on their data.

11.3 Using UPDPs and HPDPs

It is possible that a UPDP has a better science quality than the SPG products, e.g. since they were processed with a particular science goal in mind. However, use of the UPDPs should be considered with caution and it is especially important to check when they were created and with which version of the calibration tree: for photometry and spectroscopy both – but especially for spectroscopy – the flux calibration evolved through the mission, up to the very final SPG release. A careful reading of the UPDP release notes and the accompanying papers is recommended.

The PACS photometry HPDPs are in some cases a replacement for the SPG, the ‘JScanam large field maps’ and ‘Unimap extra maps’ in particular. For PACS spectroscopy, the ‘red leak’ and ‘blue spectra’ HPDP contain data that are unobtainable from the SPG products gotten from the HSA, the others contain complementary data or potentially better data. Eventually, all HPDPs will be provided directly through the HSA interface, and it will be immediately obvious when an observation has an HPDP.

Some HPDPs have no SPG alternatives, such as the PACS Point Source Catalogue. The PSC data were extracted in an automated or semiautomated way, so they are useful as a starting point but their use for scientific analysis should be critically scrutinised.

12 Appendix

12.1 Tables of product FITS filename patterns: photometry

The filenames of the FITS files that are the PACS photometry maps have the patterns described in [Table 5](#).

Table 5: The filename patterns for the photometry Level 2, 2.5, and 3 maps

Folder	Sub-folder	Filename pattern	Description
browseProduct	blue_Jscanam_map	hpacs_25HPPJSMAPB_blue_<RA>_<DEC>_00_v1.0_<NNN>	Level 2.5 SBP
	blue_Jscanam_map	hpacs_25HPPJSMAPB_green_<RA>_<DEC>_00_v1.0_<NNN>	
	red_Jscanam_map	hpacs_25HPPJSMAPR_<RA>_[plm]<DEC>_00_v1.0_<NNN>	Level 2 SBP
	blue_projected_map	hpacs<OBSID>_20hppmapb_00_<NNN>	
	red_projected_map	hpacs<OBSID>_20hppmapr_00_<NNN>	
Level 2	HPPMAP<BIR>	hpacs<OBSID>_20hppmap<blr>_00_<NNN>	projected maps
Level 2_5	HPPHPFMAPB	hpacs_25HPPHPFMAPB_blue_<RA>_<DEC>_00_v1.0_<NNN>	projected maps (scan+cross-scan)
	HPPHPFMAPB	hpacs_25HPPHPFMAPB_green_<RA>_<DEC>_00_v1.0_<NNN>	
	HPPHPFMAPR	hpacs_25HPPHPFMAPR_<RA>_<DEC>_00_v1.0_<NNN>	JScanam maps (scan+cross-scan)
	HPPJSMAPB	hpacs_25HPPJSMAPB_blue_<RA>_<DEC>_00_v1.0_<NNN>	
	HPPJSMAPB	hpacs_25HPPJSMAPB_green_<RA>_<DEC>_00_v1.0_<NNN>	Unimap maps (scan+cross-scan)
	HPPJSMAPR	hpacs_25HPPJSMAPR_<RA>_<DEC>_00_v1.0_<NNN>	
	HPPUNIMAPB	hpacs_25HPPUNIMAPB_blue_<RA>_<DEC>_00_v1.0_<NNN>	Unimap maps (scan+cross-scan)
	HPPUNIMAPB	hpacs_25HPPUNIMAPB_green_<RA>_<DEC>_00_v1.0_<NNN>	
	HPPUNIMAPR	hpacs_25HPPUNIMAPR_<RA>_<DEC>_00_v1.0_<NNN>	
Level 3	HPPJSMAP<BIR> and HPPUNIMAP<BIR>	same as Level 2.5 but '30' in place of '25'	multiple obsids combined

Table 6: The extensions in the Level 2, 2.5, and 3 photometry FITS files

Name	Description	Products found in
image	fluxes in Jy/(map pixel)	maps at all levels
coverage	a measure of the number of detector readouts that were used to set the flux in a map pixel	maps at all levels
error	estimated via the coverage using an empirical calibration established on cosmological fields computed within the framework of the mapper	HPF+PP maps Unimap maps
stDev	computed as scatter in the input detector time-line data created via projected timelines	HPF+PP maps JScanam maps
HPF Mask	the mask used in the HPF mapper	HPF+PP maps
naive	the naive map	Unimap maps
gls	the map processed with Unimap (still contains gls artifacts)	Unimap maps
pgls	the final map after removing gls artifacts in Unimap	Unimap maps

<RA> is the hour+minute, <DEC> is the degree+arcminute. <NNN> is a timestamp. The SBPs provided are Level 2.5 maps unless only Level 2 is present. All observations have a red, and either a blue or green map, however only Level 2.5 includes the words 'greenblue' in the name. The bands present at Level 3 depends on the common bands in the combined observations. The extensions in the photometry map FITS files are described in Table 6.

12.2 Tables of product FITS filename patterns: spectroscopy

The filenames of the FITS files that are the PACS spectroscopy products have the patterns described in Table 7 and the SBPs in Table 8.

<RA> is the hour+minute, <DEC> is the degree+arcminute. <NNN> is a timestamp. Most PACS products are 'sliced' (indicated with an 's' or 'S' at the end of the hps.../HPS... part of the filename), with one product of each type for each wavelength range, and the slice numbers are '<##>'. Level 3 is not sliced. All Level 2 and 2.5 products have a red and blue camera

Table 7: The filename patterns for the spectroscopy Level 2, 2.5, and 3 products

Folder	Sub-folder	Filename pattern	Description
Level 2	HPS3D[B R] /herschel.pacs.signal.PacsCube	hpacs<OBSID>_20hps3d[bl]r_s_<##>_<NNN>	earliest cube <i>not for science</i>
	HPS3DR[B R] /herschel.pacs.signal.PacsRebinnedCube	hpacs<OBSID>_20hps3dr[bl]r_s_<##>_<NNN>	native /rebinned cube
	HPSTBR[B R] /herschel.pacs.signal.PacsSpecTable	hpacs<OBSID>_20hpstbr[bl]r_s_<##>_<NNN>	rebinned cube table
	HPS3DP[B R] /herschel.ia.dataset.spectrum.SpectralSimpleCube	hpacs<OBSID>_20hps3dp[bl]r_s_<##>_<NNN>	projected cube
	HPS3DI[B R] /herschel.ia.dataset.spectrum.SpectralSimpleCube	hpacs<OBSID>_20hps3di[bl]r_s_<##>_<NNN>	interpolated cube
	HPS3DD[B R] /herschel.ia.dataset.spectrum.SpectralSimpleCube	hpacs<OBSID>_20hps3dd[bl]r_s_<##>_<NNN>	drizzled cube
	HPSSPEC[B R] /herschel.pacs.signal.PacsCentralSpectrum	hpacs<OBSID>_20hpsspec[bl]r_s_<##>_<NNN>	point-source table
	Level 2.5	HPS3DRBS[B R]/ herschel.pacs.signal.PacsRebinnedCube	hpacs_25HPS3DRBS[B R]S_<RA>_<DEC>_<##>_v1.0_<NNN>
HPSTBRBS[B R] /herschel.pacs.signal.PacsSpecTable		hpacs_25HPSTBRBS[B R]S_<RA>_<DEC>_<##>_v1.0_<NNN>	rebinned cube table
HPS3DPBS[B R] /herschel.ia.dataset.spectrum.SpectralSimpleCube		hpacs_25HPS3DPBS[B R]S_<RA>_<DEC>_<##>_v1.0_<NNN>	projected cube
HPS3DIBS[B R] /herschel.ia.dataset.spectrum.SpectralSimpleCube		hpacs_25HPS3DIBS[B R]S_<RA>_<DEC>_<##>_v1.0_<NNN>	interpolated cube
HPS3DDBS[B R] /herschel.ia.dataset.spectrum.SpectralSimpleCube		hpacs_25HPS3DDBS[B R]S_<RA>_<DEC>_<##>_v1.0_<NNN>	drizzled cube
HPSSPECBS[B R] /herschel.pacs.signal.PacsCentralSpectrum		hpacs_25HPSSPECBS[B R]S_<RA>_<DEC>_<##>_v1.0_<NNN>	point-source table
Level 3		HPSSPEC	hpacs_30HPSSPEC_<RA>_<DEC>_v1.0_<NNN>

Table 8: The filename patterns for the spectroscopy standalone browse products, found in the folder **browseProduct**

Sub-folder	Filename pattern	Description AOT
HPSTBR[B R] /herschel.pacs.signal.PacsSpecTable	hpacs<OBSID>_20hpstbr[b]r_s_<##>_<NNN>	rebinned cube table (L2)
HPSTBRBS[B R] /herschel.pacs.signal.PacsSpecTable	hpacs_25HPSTBRBS[B R]S_<RA>_<DEC>_<##>_v1.0_<NNN>	rebinned cube table (L2.5)
HPSSPEC[B R] /herschel.pacs.signal.PacsCentralSpectrum	hpacs<OBSID>_20hpsspec[b]r_s_<##>_<NNN>	point-source table (L2)
HPSSPECBS[B R] /herschel.pacs.signal.PacsCentralSpectrum	hpacs_25HPSSPECBS[B R]S_<RA>_<DEC>_<##>_v1.0_<NNN>	point-source table (L2.5)
HPSSPEC	hpacs_30HPSSPEC_<RA>_<DEC>_v1.0_<NNN>	point-source table (L3)
HPS3DEQP[B R] /herschel.ia.dataset.spectrum.SpectralSimpleCube	pacs<OBSID>_20hps3deqp[b]r_s_<##>_<NNN>	projected cube equidistant(L2)
HPS3DEQPBS[B R] /herschel.ia.dataset.spectrum.SpectralSimpleCube	hpacs_25HPS3DEQPBS[B R]S_<RA>_<DEC>_<##>_v1.0_<NNN>	projected cube equidistant (L2.5)
HPS3DEQD[B R] /herschel.ia.dataset.spectrum.SpectralSimpleCube	hpacs<OBSID>_20hps3deqd[b]r_s_<##>_<NNN>	drizzled cube equidistant (L2)
HPS3DEQDBS[B R] /herschel.ia.dataset.spectrum.SpectralSimpleCube	hpacs_25HPS3DEQDBS[B R]S_<RA>_<DEC>_<##>_v1.0_<NNN>	drizzled cube equidistant (L2.5)
HPS3DEQI[B R] /herschel.ia.dataset.spectrum.SpectralSimpleCube	hpacs<OBSID>_20hps3deqi[b]r_s_<##>_<NNN>	interpolated cube equidistant (L2)
HPS3DEQIBS[B R] /herschel.ia.dataset.spectrum.SpectralSimpleCube	hpacs_25HPS3DEQIBS[B R]S_<RA>_<DEC>_<##>_v1.0_<NNN>	interpolated cube equidistant (L2.5)

Table 9: The extensions in the Level 2, 2.5, and 3 spectroscopy FITS files

Name	Description	Product(s) found in
image	the fluxes in Jy/pixel (=spatial pixel); 3D array	all cubes
coverage	a measure of the amount of data from the input cube that created the data of the output cube; 3D array	projected, drizzled cubes
error	propagated from the stddev of the input cubes; 3D array	projected, interpolated, drizzled cubes
stddev	the stddev of the time-line data from the input cube which were averaged to create the data of the output cube; 3D array	rebinned cubes
imageIndex	the 1d dataset of the wavelengths in the cube	all cubes
wcs-tab	a wavelength lookup table (WCS-compliant)	all cubes
ra, dec	sky coordinates; 3D array	rebinned cubes
exposure	a measure of the amount of time-line data from the input cube that created the data of the output cube; 3D array	rebinned cubes
flag	an array that contains values based on the masks computed by the pipeline, these data having been excluded from the current cube (difficult to readout outside of HIPE)	all cubes
spectra	a table of the spectral data	all tables

version, indicated by '[blr]' in the filename and '[BLR]' in the directory name. The reason for the difference in the filenames between Level 2 and 2.5/3 is purely to fit in with the general *Herschel* convention.

The extensions in the spectroscopy FITS files are described in Table 9.

12.3 AOT-related FITS file keywords

As explained in Secs 3.5 and 3.5.1, it is useful to know the AOT of any observation you get from the HSA. These can be found in the keywords of a map, cube or spectrum table FITS file taken from any Level in the observation. The main keywords are found in extension 0 (which is just a header, it contains no data). Each extension also has its own keywords, specific to those datasets. Tables listing most of the keywords and their description can be found in the [PACS Handbook](#). Here we give the AOT-related keywords: in Table 10 for photometry, and Table 11 for spectroscopy.

An additional dataset for spectroscopy has been provided on [HELL \(level 3\)](#). This is a spreadsheet containing the important AOT-related keywords and their values for *all* PACS spectroscopy observations in the HSA. The keywords are: all of those listed in Table 11, the wavelength ranges that were requested and which are eventually contained in the observations, and the slice number (Sec. 3.3) of all the the FITS files in Level 2/ 2.5 and the wavelength range contained in those slices. The spreadsheet and a README can be gotten directly from [here](#).

12.4 Spectroscopy point-source tables: how they were calculated

For point sources, it is generally not enough to sum up the flux in the field but rather aperture corrections need to be applied to suitably-extracted spectra. These aperture corrections have been

Table 10: Useful AOT-related photometry keywords

Description/Obs. mode	FITS keyword	Value
chop-nod/point source	OBS_MODE	Point-source photometry
scan mapping	OBS_MODE	Scan map
SPIRE-PACS parallel	OBS_MODE	Parallel mode
scan speed	SCANSP/SCANVELO	slow/medium/fast; arcsec/s
camera	CAMNAME/CAMERA	red or blue camera
blue filter	BLUEBAND	blue1 (blue), blue2 (green)

OBSIDLST: a list of obsids (scan map AOT only)
The list of obsids that were observed sequentially and combined:
If 2: these are a scan+cross-scan pair; If 4: they are a scan+cross-scan pair for a 70+160 μm and 100+160 μm filter combination; If not present: there is only a single scan map observation

Table 11: Useful AOT-related spectroscopy keywords

Observing mode	FITS keyword	Value
chop-nod	CHOPNOD	True
unchopped, wavelength switching	CHOPNOD	False
line scan	INSTMODE	PacsLineSpec
range scan	INSTMODE	PacsRangeSpec
pointed	OBS_MODE	Pointed
mapping	OBS_MODE	Mapping

Mapping mode keywords:
number of raster steps RASSTEPL, RASSTEP
raster step sizes (") NRASTCOL, NRASTLIN

Wavelength keywords:
wavelength MIN|MAXWAVE (ignore MEANWAVE)

computed from the knowledge of the PACS spectroscopy beams. The details of the point-source calibration and the beams are given in the [PACS Handbook](#).

The particular HIPE task to use to extract the spectrum and apply the corrections depends on where the point source is in the field. The task which is the easiest to run is applicable to centred and very slightly off-centred point sources, and requires the rebinned cubes (in the HPS3DR[R|B] directory) as input. For off-centred sources, point sources in mapping observations, or point sources blended with other sources, alternatives are available. Which output of the task to use for different locations of point source in the FoV, and what the various alternatives are, see the user note [Dealing with point sources](#) and in the [PACS Handbook](#). Here we introduce the task used to create the data in the point-source spectrum table that can be found in a all pointed observations: HPSSPEC[B|R] (Level 2) and HPSSPECBS[B|R] (Level 2.5), or HPSSPEC (Level 3).

The HIPE task is called *extractCentralSpectrum*, and it produces three output spectra:

1. ‘c1’ has had the point-source correction applied to the spectrum extracted from the central spaxel. It is the recommended product to use for a faint sources from unchopped and chop-nod observations, where almost no flux can be seen from the source outside the

central spaxel.

2. **'c9'** is the sum of the central 3×3 spaxels with the the point-source correction applied. The total spectrum from the central part of the FoV contains more of the flux of the source than the central spaxel does alone, especially for middling and bright sources (where it is obvious that the surrounding spaxels also contain source flux). For observations with slight pointing offsets or jitter – where the source could have moved slightly out of the central spaxel – this 3×3 'super spaxel' is also a better representation of the source than the central spaxel alone. This is the product to use for sources where it is clear that there is emission in most of the central 3×3 spaxels, and for unchopped observations is the recommended product for most sources.
3. **'c129'** is a combination: the spectrum of c1 (which probably has the better SNR) on the flux level of c9 (which is usually brighter than c1). This is the recommended product to use for brighter sources – where it is clear that there is emission in most of the central 3×3 spaxels – for chop-nod observations. It should not be used for unchopped observations.

It is important to note that for the data of this table to be suitable for science use, it must already be known that the target is a point source and it must be located in the central region of the rebinned cube the task is applied to. (Hence it will be necessary to open the rebinned cube in a cube viewer to check on that.) The use of this task is explained in the [PACS Data Reduction Guide \(spec\)](#). As a courtesy to users, *extractCentralSpectrum* was run on all the Level 2 and 2.5 rebinned cubes in all pointed observations (regardless of the type of target), and the data (c1, c129, c9, and the central spaxel's uncorrected spectrum) were placed in the spectrum table product.

12.5 Acronyms

AOT	Astronomer Observation Template, i.e. the observation request details
FMT	Forward modelling tool
FoV	Field of View
FWHM	Full Width Half Max
HELL	Herschel Explanatory Legacy Library
HPDP	Highly Processed Data Product (provided for some observations at the HSA)
HPF+PP	High-pass filter and photProject tasks to create photometry maps
HSA	Herschel Science Archive
HSC	Herschel Science Centre
IFU	Integral field unit
obsid	observation identification number (1342...)
PSF	Point Spread Function ('beam' is the PSF as imaged by the detector and the map/cube-making process)
SBP	Standalone browse product
SNR	Signal-to-noise ratio
spaxel	spatial pixel: one patch of sky with a full spectrum; can be used to refer to the physical spaxel of the instrument, or a projected spatial pixel of a mosaic cube
SPG	Standard Product Generation (automatic pipeline run at the HSC)
SSO	Solar System Object
WCS	world coordinate system (in FITS files)

12.6 Links

	Documentation
Data Products Known Issues	http://herschel.esac.esa.int/twiki/bin/view/Public/DpKnownIssues
Decision tree	https://www.cosmos.esa.int/documents/12133/996891/Product+decision+trees/
FMT package	https://www.cosmos.esa.int/documents/12133/996891/PACS+Spectrometer+-+Forward+Model+Tool+for+science+use
HELL	https://www.cosmos.esa.int/web/herschel/legacy-documentation-pacs (Level 1 and 2 contain the most relevant documents)
PACS Data Reduction Guide (phot)	http://herschel.esac.esa.int/hcss-doc-15.0/print/pacs_phot/pacs_phot.pdf
PACS Data Reduction Guide (spec)	http://herschel.esac.esa.int/hcss-doc-15.0/print/pacs_spec/pacs_spec.pdf
PACS Overview page	https://www.cosmos.esa.int/web/herschel/pacs-overview
PACS Quick-Start Guide (phot)	https://www.cosmos.esa.int/documents/12133/996891/PACS+Photometer+Quick+Start+Guide
PACS Quick-Start Guide(spec)	https://www.cosmos.esa.int/documents/12133/996891/PACS+Spectrometer+Quick+Start+Guide
PACS Handbook	http://www.cosmos.esa.int/documents/12133/996891/PACS+Explanatory+Supplement/
Products Definition Document	http://herschel.esac.esa.int/hcss-doc-15.0/print/pdd/pdd.pdf
Scanamorphos	http://www2.iap.fr/users/rousseau/herschel/
Unimap	http://infocom.uniroma1.it/unimap/docs.html

	Data
ADPs	http://archives.esac.esa.int/hsa/legacy/ADP/
AOT header keyword CSV file	http://herschel.esac.esa.int/twiki/pub/Public/PacsCalibrationWeb/AOTMetaData.tar
Beams	modelled: http://archives.esac.esa.int/hsa/legacy/ADP/PSF/PACS/Modelled/
Beams photometry	http://archives.esac.esa.int/hsa/legacy/ADP/PSF/PACS/PACS-P/
Beams spectroscopy	archives.esac.esa.int/hsa/legacy/ADP/PSF/PACS/PACS-S/
Calibration source models	https://www.cosmos.esa.int/web/herschel/calibrator-models
Calibration source models (PACS-S)	The http://archives.esac.esa.int/hsa/legacy/ADP/PACS/PACS-S_calibrators/
Calibration files	http://archives.esac.esa.int/hsa/legacy/cal/PACS/user/
HPDPs	http://archives.esac.esa.int/hsa/legacy/HPDP/PACS/
HPDPs (JScanam)	http://archives.esac.esa.int/hsa/legacy/HPDP/PACS/PACS-P/JScanam/
HPDPs (Red leak)	http://archives.esac.esa.int/hsa/legacy/HPDP/PACS/PACS-S/red_leak/
On/Off-source range-scan obsids	http://herschel.esac.esa.int/twiki/pub/Public/Level-2_5Products/PACS_Spectrometer_Level2_5_v14.2.txt
PACS Point Source Catalogue	http://archives.esac.esa.int/hsa/legacy/HPDP/PACS/PACS-P/PPSC/
UPDP web-page	www.cosmos.esa.int/web/herschel/user-provided-data-products