PACS-S pipeline products and their science-readiness

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ESAC

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Telemetry

Pre-processing
- AOT independent Engineering Conversions
- First calibrations
- Advanced processing
  - Combined on and off Level 2 for unchopped range AOTs

Key processing steps
- Level 0: time domain: raw data
- Level 0.5: coordinates and wavelengths added
- Level 1: wavelength domain: partially calibrated
  - first cubes produced unchopped AOTs: flux calibration
  - spectral flatfielding chop-nod AOTs: flux calibration
  - mosaic cubes created
  - spectral tables created
- Level 2: wavelength domain: fully calibrated
- Level 2.5
- Level 3: spectral tables for pointed chop-nod AOTs, full SED only

Context
- Combined Level 2 for pointed chop-nod AOTs, full SED only
- Quality control: automatic flags
- Quality control: manual quality inspection
- Quality Summary
Level 0 and 0.5 are time-line spectra: a collection of data-points at each grating step, from all 16 pixels of each of the 25 modules, all thrown together. Instrumental corrections and the first level of fluxes, wavelength, and sky coordinate computations are done. Level 0.5 data are not fully calibrated.

Level 1 contains the first cubes of the pipeline, but these are also not for science use.

Level 2/2.5 contains a collection of cubes – native and mosaic – and spectral tables. What types of products are present depends on the observing mode (AOT).
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From raw to native cube

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From native cube to tables

- Native cube has the footprint of the PACS IFU
- Better known as *rebinned cube*; are science-grade for point and point-like sources
- The WCS is not a regular grid → hard to read into cube viewers outside HIPE
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For all observations, and to provide a product easier to read outside of HIPE, the data of each spaxel are converted into table form: wavelength, flux, error, ra, dec, spaxel coordinate, and raster position – rebinned cube table
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- For all pointed observations, we also provide the point-source calibrated spectrum (in Jy; created by the task extractCentralSpectrum) as a table – (point-source) spectrum table
  - This product should be used with care: no determination that the target is a point source, or that it is centred and not contaminated has been made
  - There are 2 or 3 versions of the point-source calibrated spectrum provided: see the documentation* to learn more

* PACS Data Reduction Guide, PACS Products Explained, or PACS Handbook
Native (rebinned) cube has the footprint of the PACS IFU

*Mapping* observations are a raster of individual pointings, and these are combined into a single *mosaic cube* by the pipeline. Mapping observations were done to overcome the problem of a single pointing spatially undersampling the beam, or they were done to observe a larger field on the sky.

Three approaches are offered*:

- **interpolated cubes**: Spectra are interpolated from the input cubes onto the output cube spatial grid to create the mosaic cube
- **projected cubes**: Spectra are combined according to the overlapping areas of the spaxels of the input and output spatial grids
- **drizzled cubes**: Spectra are “drizzled” from the spaxels of the input cubes onto the spaxels of the output cube

* These tasks are explained in the PACS Data Reduction Guide
From native cube to mosaic cube

Native (rebinned) cube has the footprint of the PACS IFU. Mapping observations are a raster of individual pointings, and these are combined into a single mosaic cube by the pipeline. Mapping observations were done to overcome the problem of a single pointing spatially undersampling the beam, or they were done to observe a larger field on the sky.

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- Interpolated cubes: Spectra are interpolated from the input cubes onto the output cube spatial grid to create the mosaic cube.
- Projected cubes: Spectra are combined according to the overlapping areas of the input and output grid spaxels.
- Drizzled cubes: Spectra are “drizzled” from the input cubes onto the output mosaic cube grid.

* These tasks are explained in the PACS Data Reduction Guide.
Observations have different Levels in them, but you are only interested in Levels 2, 2.5, or 3. Levels 2.5 and 3 are offered for certain sub-sets of observations, Level 2 for all.

The rebinned cubes and rebinned cube tables are offered for all observations at these levels.

Point source spectrum tables are offered for some observations.

For all observations, 2 of 3 of the different types of mosaic cubes are also provided.

Pointed and tiling observations undersampled the beam. Nyquist and oversampled mapping observations (obviously) sample the beam well. The types of cubes you get vary depending on the mapping mode details.

* These tasks are explained in the PACS Data Reduction Guide.
- Download a tarball (an entire observation) on disk and unpack it
- Raw to SPG (standard product generator – i.e. automatic pipeline produced) product (Levels 0 to 2, 2.5, 3) are present
  - Level 0—2 *for all* observing modes
  - Level 2.5 only *for unchopped range* scans
  - Level 3 only for *chop-nod pointed SED* scans
- Directory names indicate the type of product (type of cube, type of table)

- **Herschel Pacs Spectroscopy 3D** (cube): HPS3D

- Red or Blue camera

- **Herschel Pacs Spectroscopy Spectrum** (table): HPSSPEC

- **Herschel Pacs Spectroscopy Table (of the) Rebinned** (cube): HPSTBR
Directory names indicate the type of product (type of cube, type of table)
An ObservationContext on disk

- Products from the Level 2.5 and are the background subtracted ("BS") cubes and tables: the Level 2 of the on-source obsid with the Level 2 of the off-source obsid subtracted.
- They are found in unchopped range scans only.
An ObservationContext on disk

- FITS file names indicates obsid ("hpacs1342xxx"), level ("20, 25, 30"), product type ("hpsxxx"), camera ("r|b"), and slice number (00,01...)
- Slice number: there can be several of the same product in a directory: one for each wavelength range and pointing – these are called “slices”
FITS files contain several datasets (see the PPE* and PACS Handbook for a break-down): image (fluxes), weights (error), flags, quality summary, ... First extension is empty, but it contains the full header.

<table>
<thead>
<tr>
<th>Index</th>
<th>Extension</th>
<th>Type</th>
<th>Dimension</th>
<th>View</th>
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* PPE– PACS Products Explained
Standalone Browse products: are based on Level 2, 2.5, and 3 and are found in the “browseProduct” directory as well as the Level directories. Are also included as a direct download from the HSA.

SBPs include the spectrum tables and EQuidistant cubes: one of the mosaic cubes spectrally interpolated onto a very fine, equidistant wavelength grid.*

* All other cubes have a regular spectral grid but the bin sizes scale with wavelength (to evenly sample over the whole wavelength range). This can make it difficult to read these cubes, as the WCS is not regular.

Equi cubes are created by regridding on a fine spectral grid: the fluxes are practically identical.
Rebinned cubes and rebinned cube tables are provided for all observations.
Level 2/2.5 point-source spectrum tables are only provided for pointed observations.
Level 3 spectrum tables are only provided for pointed chop-nod SEDs.
The mosaic cubes (drizzled, interpolated, projected) provided depends on the observing mode.
The mapping mode is given in keywords* in the all cube FITS files.

* See the the PACS Handbook or the PACS Products Explained for full details.
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<th>Oversampled</th>
<th>Nyquist sampled</th>
<th>Undersampled (tiling/pointed)</th>
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<tbody>
<tr>
<td>Cube type</td>
<td>line</td>
<td>range</td>
<td>line</td>
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<tr>
<td>drizzled</td>
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<td></td>
<td>✔</td>
</tr>
<tr>
<td>projected</td>
<td>✔</td>
<td>✔</td>
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</tr>
<tr>
<td>interpolated</td>
<td></td>
<td>✔</td>
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Rebinned cube tables are provided for all observations.
Level 2/2.5 point-source spectrum tables are only provided for pointed observations.
Level 3 spectrum tables are only provided for pointed chop-nod SEDs.
Both the background subtracted (Level 2.5) and on-only or off-only products are provided for unchopped range scans.
The equidistant cubes provided are:

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<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>equi projected</td>
<td></td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>equi interpolated</td>
<td></td>
<td>✔</td>
<td></td>
</tr>
</tbody>
</table>
For unchopped observations, the continuum level carries quite a high absolute uncertainty. Reducing the data through the last steps of the pipeline may help, however this observing mode was never guaranteed to produce a good continuum.

You are should work on the latest (and final) products of the archive (14.2)

All cubes have flux units of Jy/spaxel aka Jy/spatial pixel. That is, whatever the area of the spaxel of the cube you are looking at, the flux is the Jy in that area.

Point-source calibrated products have units of Jy.

The standard products in the HSA are cut off below 55µm and above 190µm. The very blue end will be provided as uncalibrated products in the HSA, and the red order leak end will be provided, calibrated, as HPDPs.
For point sources observed as:
- pointed only (no mapping)
- chop-nod or unchopped
- line or range

The fully-calibrated spectrum can be taken from the *point-source spectrum tables* (Level 2/2.5/3) or can be created with a single task in HIPE from the *rebinned cubes* (Level 2/2.5)

Prerequisites for the correction:
- The source is centred within the central spaxel
- The spectrum is of the source only – no contamination
Science readiness: semi-extended sources

For sources that fit easily within the central 3x3 spaxels (<15” diameter) from:

✧ pointed only (no mapping)
✧ chop-nod or unchopped
✧ line or range

The fully-calibrated spectrum of the source can be extracted from the rebinned cubes with the aid of two tasks in HIPE

Prerequisites for the correction:

✧ The source fits within the central 3x3 spaxels and is centred on the central one
✧ The spectrum is of the source only – no contamination
✧ The surface brightness distribution of the source is known
For fully extended sources (<20% gradient over the FoV) from:
- pointed or mapping
- chop-nod or unchopped
- line or range

All cubes are fully calibrated
For extended sources that have visible structure (i.e. have >20% gradient over the FoV) from:
- pointed or mapping
- chop-nod or unchopped
- line or range

The cubes are not fully calibrated. To have cube with a fully-calibrated surface brightness it will be necessary to use HIPE to do a “forward modelling” to predict the correct flux levels (in a wavelength dependent way) – this will be discussed later.

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- The surface brightness distribution of the source is known