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DOCUMENT

PACS Spectrometer HPDP: The Pointing Offset Correction point-source calibrated spectra

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1   INTRODUCTION

This release note concerns the PACS Spectroscopy Highly Processed Data Products produced with the "POC" pipeline script.

The standard (SPG) products provided for PACS spectroscopy observations in the Herschel Science Archive (HSA) include tables of point-source calibrated spectra. These are provided only for pointed observations, with the assumption that point sources would have been observed primarily in this mode. These tables are provided *regardless of whether the target is a point source or not* – the user needs to establish the point-like nature of the target for themselves. A guide to working with point sources can be found in the document "Dealing with point sources observed with PACS spectroscopy". The point-source calibrated spectra that are provided in the observations are extracted from the Level 2 or 2.5 re-binned cubes, i.e. those created by the standard pipeline for the observing mode of each observation, and are created with the task extractCentraSpectrum.

In the "PACS Pipelines" menu of the Herschel software (HIPE), there is an alternative interactive pipeline that can potentially provide better spectra of point sources than the SPG pipeline can produce. This is the "Pointing Offset Correction" (POC) pipeline, which can be used on line- and range-scans, on pointed and mapping observations, but only those of the chop-node mode. The conditions under which better spectra can be produced, and what "better" means, are explained later in this release note. Generally-speaking, this pipeline is suited to brighter sources, and produces better spectra for point sources that are offset from the central spaxel, but still located within the central 3x3 spaxels, of a re-binned cube. (For more information about "re-binned cubes" see the PACS Products Explained; what the "3x3" central spaxels means is explained in the document "Dealing with point sources observed with PACS spectroscopy").

The POC pipeline is a full data-reduction pipeline and is similar to the SPG pipeline for the same observing mode, but it has additional pointing-offset correction tasks. These attempt to identify the offset of a point source from the centre of the FoV and to correct the flux of the cube accordingly. The end result of the pipeline are the same tables of point-source calibrated spectra that are also found in the SPG download, created from the Level 2 re-binned cubes that are the end product of this POC pipeline. Note that it is only the point-source calibrated data that are a science result of the pipeline, *not* also the cubes themselves.

The POC pipeline is interactive: the parameters of the POC tasks can be adjusted for fainter/brighter or more-/less-offset sources. In addition, the diagnostic outputs should be inspected by the user, and the resulting spectra should be compared with the equivalent SPG spectra. The specific POC tasks in the pipeline are explained in the PACS Handbook and a

technical note can be found on the HELL pages (PACS section Level 2). The POC pipeline uses the "telescope normalisation" calibration method (this is explained in the PACS Handbook). This method is also used by the SPG pipeline for chop-nod observations, and in fact will only work for that observing mode: it is for this reason that the POC pipeline will only work on chop-nod observations.

With the understanding that archive users may be reluctant to use HIPE and to run a pipeline, if it is not clear how much of an improvement this can make for their point sources, it was decided to run the POC pipeline and provide the results as this POC HPDP. All pointed, chop-nod observation were processed with this pipeline. We stress that this was done *regardless of whether the target is a point source or not* – the user needs to establish the point-like nature of the target for themselves.

Before reading this release note you should be familiar with PACS spectroscopy, in particular with the various observing modes that were used and different types of cubes that were produced. These are explained in the Quick-Start Guide, and in more detail in the PACS Products Explained and the PACS HandbookC:\Users\mkidger\AppData\Local\Temp\HYPERLINK, all of which can be found in the Herschel Explanatory Legacy Library (PACS section). To follow the advice given in this release note, the user should have at least read the Quick-Start Guide, and should know what observing mode their observation was taken with. Definitions are provided at the end of this release note, but to *understand* the terms defined, it is necessary to read the other documentation.

Clearly, if your source is not a point source at the PACS wavelengths (or is not very close to being one), all of the output of this HPDP pipeline script is useless.

2 DESCRIPTION OF THE HPDP

2.1 How the HPDPs were created

The POC pipelines that are provided in HIPE – one for line and short range (<5 μm) scans, and another for longer ranges and the full SED – were used to create these HPDPs. No adjustments were made to the pointing offset tasks as written into the pipeline scripts, even for the cases where the tasks failed to complete on an observation. "Failure to complete" usually occurred when:

- The Level 0 products were slicedRamps rather than slicedFrames. While the SPG pipeline could deal with this, the POC pipeline could not. The observations that failed for this reason were all taken in the first months of the mission, while the observing methods (the AOTs) were still evolving.
- The POC tasks failed to locate the source: most likely because it was too faint, too offset,

or not sufficiently point-like.

For the second case, it may be that adjusting the parameters of the POC tasks will result in a successful processing of an observation. A list of the observations that have been processed for this HPDP can be found here on the HPDP pages. If your observation is not on this list but you want to try the POC script anyway, you will need to install and use HIPE.

2.2   The HPDP products

The results of the POC HPDP pipeline are the point-source calibrated spectra, one for each wavelength range in the observation. Note that data in the blue edge (50–55 μm) and the red leak range (190–206 μm) have not been processed.

The HPDP point-source spectra are created in the POC pipeline from its final Level 2 re-binned cubes using the task extractCentralSpectrum. The procedure is exactly the same as is followed by the SPG pipeline. A very important difference between the SPG pipeline and the POC pipeline is that for the second, *only* the point-source spectra are valid products to use for science. The re-binned cubes are *not* to be used, and it is for this reason that they are not provided in the HPDP. Users wishing to inspect the cubes need to use those taken from the SPG download of the observation instead.

The reason why the cubes are not a valid science product when processed by the POC pipeline lies in the nature of the correction that the POC pipeline applies. This is explained in the previously-mentioned documentation. The offset of the source is computed by comparing the observed flux distribution of the central 3x3 spaxels to the flux distribution expected for a centred point source. Once the offset has been computed, the summed flux of the central 3x3 spaxel region of the cube is corrected. This means that inspecting these cubes is not useful, as the flux distribution no longer informs on the location of the point source in the FoV. In addition, because the correction is done on the *each of the spaxels* of the 3x3 spaxel region, the spectrum taken *only* from the central spaxel is not useful: that taken from the 3x3 should be used instead.

The output of extractCentralSpectrum were placed in the same point-source table that is also provided in an SPG download. Only the two point-source results that are valid for POC-produced cubes – c9 and c129 – are included in the table. The spectrum of the central spaxel (not point-source corrected) is also provided in this table, but the user should note that this spectrum is also invalid and *should be ignored*. The task extractCentralSpectrum is explained in the PACS Handbook and in "Dealing with point sources observed with PACS spectroscopy".

The naming convention for the point-source tables is the following:

hpacs<OBSID>_20hpsspec<b|r>_POC_<SLICE NO.>.fits

where:

- hpacs: Herschel PACS
- OBSID: is the 1342xxxxxx observation identification number.
- 20hpsspec: from pipeline Level 2.0, Herschel-PACS-spectroscopy-point-source-table
- b|r: indicates blue or red camera
- POC: pointing offset correction output
- SLICE NO.: the different wavelength ranges in any observation are indicated as a "slice" number. The same slice numbers as found in the SPG product are also found here: slice 00 in the HPDP product will be the same wavelength range, for that camera, as slice 00 in the SPG product. The wavelength range of the slice can be found either by opening the cube in an appropriate viewer, or looking for the keywords MINWAVE and MAXWAVE in the FITS file (extension 0). Alternatively, a [spreadsheet](#) containing all the relevant AOT-related keywords and the wavelength-vs.-slice information can be found on the Herschel Legacy Library ([PACS](#) section level 2).

2.3 The diagnostic products

A few diagnostic products are also provided with this HPDP. There include two sets of plots – one from the POC tasks and one from extractCentralSpectrum – and one text file of information provided by same two tasks.

- The plots created by the POC tasks show the determination of the position of the centre of the point source in the footprint of the PACS IFU (one plot shows the central 3x3 region of the IFU and the second plot is a zoom on the very centre). The values included in the text file are a summation of the numbers that are plotted: the mean and stddev of the offset in the two instrumental directions, z and y, for each slice (Frame) processed.
- The plots produced by extractCentralSpectrum show the diagnostics produced by that task that can help the user assess how useful the correction deduced is. The values include in the text file are these same diagnostics – one "median correction" and an uncertainty on that correction.

2.3.1 The POC diagnostics

Before inspecting the two sets of diagnostics provided by the POC tasks, the user should be aware of the following. At the beginning of the pointing offset computation task-block in the pipeline, the data (slicedFrames at this point) are sliced on nod, grating direction, and wavelength. In the chop-nod AOT used for most of the mission, each observation has at least one nod sequence with two nods (B and then A) and two runs along the grating (direction down and then up). Therefore, the slicedFrames are split into 4 separate Frames for each wavelength range in the camera being processed, but more if the observer had requested repeats of the

nodding or of the wavelength scanning. However, only a single spectrum is produced at the end of the pipeline for each wavelength range. There are, therefore, more "slices" processed by the POC tasks, and mores slices reported on in the diagnostic plots (and printouts), than there are final spectral products. (To know how many nod cycles and how many grating scan repetitions were asked for in any observation, consult the PACS observation summary, which is part of the SPG download but which is only visible in HIPE – this summary will also be provided in the HSA search results page soon.)

<u>The diagnostics provided by the POC tasks are the following</u>

- **A plot of the pointing offset values**, as produced by a mildly-modified version of the pipeline task plotPointingOffset. (The modifications were cosmetic in nature.) Two plots were produced for each camera, one being a zoomed version of the other. The plots are called
  JitterPlot_<OBSID>_<CAMERA>[_zoom].pdf.
  To understand the plots, the user needs to note the following:
  - A plot shows the location of the central 3x3 spaxels of the FoV (equivalent to the central 3x3 spaxels of a re-binned cube). The spaxel coordinates are printed alongside the red dots that mark the centre of each spaxel. These are the same coordinates that you see when opening a Level 2 re-binned cube (as taken from the SPG download) in HIPE with the cube viewer or the spectrum explorer, although the view is rotated and flipped with respect to the orientation in the plot. Spaxel 2,2 is the central spaxel.
  - For each slice that was processed by the POC tasks, the computed location of the source is indicated with a coloured symbol, with the key printed below the plot. For the example plot shown here, slices 0 and 1 are for nod B for the two grating scans, and slices 2 and 3 are the two grating scans for nod A. If your observation has many slices (many wavelength ranges or many repetitions on the nod or scans), this plot can take a while to read. However, in general we find that (for genuine point sources) all slices (of sufficient signal level) for each nod are clustered around the same point, and that it is not uncommon for nod A and nod B to be located slightly differently to each other.
  - The axes of the plot are in the plane of the instrument – the Z and Y direction of PACS, which is fixed to the telescope plane. To know what the coordinates are in RA and Dec, i.e. on the sky, you can (A) open a re-binned cube from Level 2 from the SPG download of your observation, and compare the location of the dots and the spaxel coordinates from the plot to those you read off from the cube viewer or spectrum explorer in HIPE. As these tools report both RA and Dec and the spaxel coordinates, this will translate the one into the other. (B) You can also open the PACS spectral footprint viewer in HIPE: this opens on an image of your source (e.g. a PACS photometry image taken from the HSA), onto which you drag and drop the slicedRe-binnedCubes of Level 2 of the SPG download. The sky coordinates and the spaxel

coordinates can then be read from the viewer. This second method is slightly more accurate that the first.

- **A text file of pointing offset values.** The same pointing offset information were printed to file called <OBSID>_jitterValues.txt, which contains the results for the red and blue camera for each slice that was processed.

An example POC diagnostic plot is shown in Fig 1.

2.3.2 The extractCentralSpectrum diagnostics

The diagnostics produced by extractCentralSpectrum are created from running the task on the Level 2 slicedRe-binnedCubes taken from the SPG download, *not* from the POC processing. The reason for that is that these diagnostics are based on a comparison of two of the point-source calibrated spectra produced by the task – c1 and c9 – and the "raw" spectrum taken from the central spaxel: however, since both c1 and "s1" are invalid when taken from cubes produced by the POC processing, these diagnostics are not useful when extractCentralSpectrum is run on the POC cubes. However, the diagnostics are useful *even if* the POC point-source spectra are to be used for science rather than the SPG point-source spectra. This is because they give an indication as to how centred and how point-like the target is. This diagnostic is explained in "[Dealing with point sources observed with PACS spectroscopy](#)" and that explanation will not be repeated here. The important points are the following:

1. If the diagnostic returns a value too high (a "median correction" of >= 1.2—1.3), it indicates that the source is either not a point-source and/or is off-centred. In this case, the point-source calibrated spectra contained in the SPG download carry a large uncertainty.
2. A non-centred point source or a source that is not a point source will *both* create a high diagnostic value – the effect of the two cannot be distinguished from each other. If you are 100% certain that the source *is* a point source, only then does a high diagnostic value indicate that the source is off-centred from the centre of the FoV.
3. If the off-centring is such that the point source is still within the central 3x3 spaxels, then the point-source spectra produced by the POC pipeline will at least as good as, and often in fact better than, the SPG spectra.

The diagnostics produced by extractCentralSpectrum are the following

- **A plot of point-source corrections**. One of the plots produced extractCentralSpectrum is provided. A separate plot for each camera and each slice of the Level 2 slicedRe-binnedCubes is created. Remember that the slicedRe-binnedCubes *of the SPG download, not from the POC script*, is used to create this plot.
  - The plot is called ExtractCentralSpectrumDiagnostics_<OBSID>_<CAMERA>_<SLICE>.pdf.
  - The curves show the "C129 scaling curve", which is the point-source corrected

spectrum taken from the central 3x3 (c9) divided by the spectrum of the central spaxel (s1), which is also the scaling curve used to create c129; the "Compared to P.S" curve, which is the ratio of the spectrum of the central spaxel to that of the central 3x3 spaxels (s1/s9) compared to the ratio expected for a perfectly centred point source. If this ratio is larger than 1.2 or 1.3, then it is likely that the source is not centred and/or not a point source.

- **A text file of point-source diagnostics**. The mean of the plotted values are printed to the same text file (<OBSID>_jitterValues.txt) that contains the pointing offset values. The value that is the "comparison to a point source" curve from the plot is given, as is the relative error (based on the spectral data that the correction is computed from), and the RMS of the spectral data. One set of three values is provided for each spectrum produced (i.e. one per wavelength range of the observation).

An example diagnostic plot produced by extractCentralSpectrum is shown in Fig. 1.
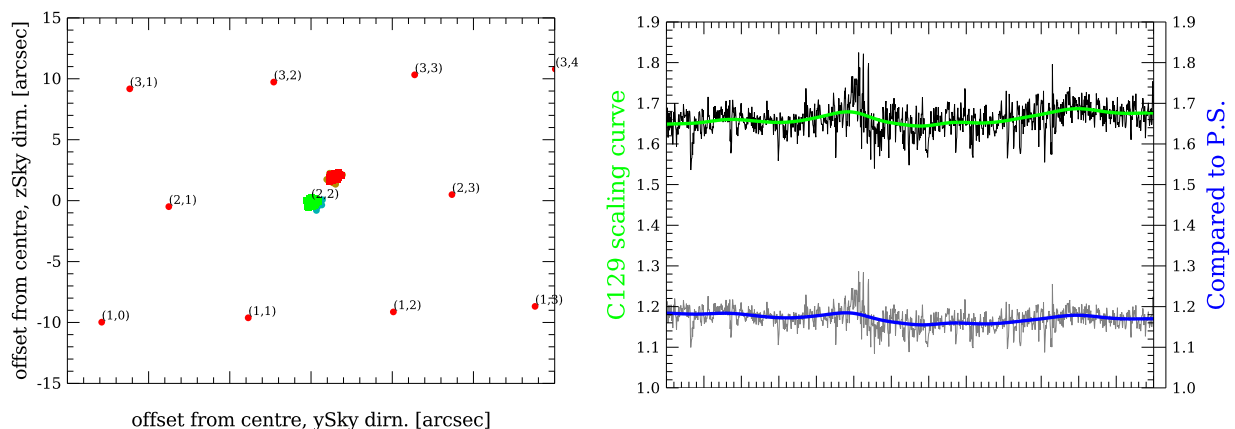

Figure 1 Left: Jitter plot showing the offsets determined by the POC tasks for the point source R Dor. Spaxel coordinates are indicated, coloured symbols are the measured positions for each data slice**. Right:** output of extractCentralSpectrum for the same observation, showing the difference between the flux in the central spaxel to the flux in the point-source calibrated spectrum called c9, and the ratio of the flux of the central spaxel to the central 3x3, compared to that for a perfectly-centred point source: values lower than 1.3 are consistent with the target being a centred point-source.

2.4   The postcards

One postcard per observation is provided. In this postcard are a series of plots: c1, c129, and c9 produced from the SPG re-binned cubes, and c9 and c129 produced by the POC HPDP

pipeline. For the line and short range scan observations, only the prime wavelength ranges are included in the postcard (i.e. those requested by the observer), for the long range-scan and SED observations, the prime and parallel ranges are both included.
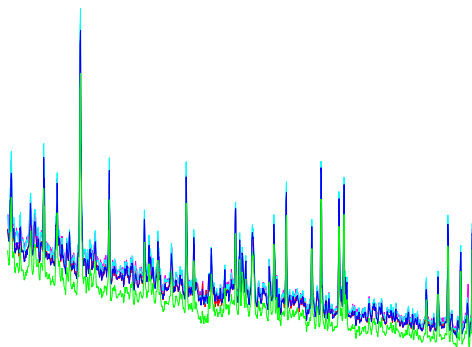
Figure 1: the postcard for an observation of the point source R Dor. The spectra are the output of extractCentralSpectrum run on the SPG cubes and the POC HPDP cubes. The differences for this source are not great, as the source was well centred anyway.

2.5   HPDP queries via the HSA

The HPDPs are served directly as gzipped files in the HSA interface when inquiring for HPDPs, and are offered also in the results from a general search. The spectral tables (FITS), the plots, and the text file are included.

3   HOW DO THE HPDP AND SPG PRODUCTS COMPARE?

3.1   What are c1, c9, and c129?

Three spectra are produced by extractCentralSpectrum: c1, c9, and c129.
The point-source spectrum c1 used the first point-source calibration established by PACS to use in the flux calibration of all PACS data (which is based on observations of fiducial point sources). The spectrum of the central spaxel is corrected for the flux missing outside of that spaxel due to the broadness of the PSF. This is the basic correction for point sources.
The point-source spectrum c9 used the second calibration determined by PACS. This was done when it was realised that for point sources with pointing jitter or slight (a few arcsec) offsets,

the calibration using the sum of the central 3x3 spaxels, with the appropriate point-source correction, was more robust than that using central spaxel only.

The point-source spectrum c129 was developed for cases where the SNR of the spectrum from the central spaxel is superior to that from the central 3x3 spaxels. Here, the spectrum from the central spaxel ("s1") is scaled to the flux level of the point-source spectrum c9, to keep the SNR of the first but the more correct fluxes of the second.

In general, c1 is the best for faint sources where no source flux falls outside of the central spaxel, c129 is best for brighter sources that are fairly well centred in the central spaxel, and c9 is best for brighter sources with a significant offset. The faint/bright centre/offset limits are not well defined, however more specific advice is given in "[Dealing with point sources observed with PACS spectroscopy](#)".

One important fact to note is that it is a basic assumption of extractCentralSpectrum that *the data are of the point source alone*, not contamination from e.g. a background or adjacent source. The calibration applied to the extracted spectra is multiplicative.

3.2   When to use the POC and when to use the SPG spectra?

It is always recommended that the user compares the POC and the SPG point-source spectra to each other. That with the most flux will usually be the better spectrum to take. It is also recommended to look at the pointing offset jitter plot and text information provided with the spectral tables for each observation in this HPDP, since this allows one to assess not just how large the offset of the point source is, but also how well it was determined. If the scatter in the values for different slices is large, then it was clearly difficult for the POC tasks to measure the offset for that source. For faint sources – of < 10Jy for example – or noisy sources (of any flux level) this is especially true.

Tests that were carried out with raster observations of the source R Dor and with synthesised point-source PACS cubes, show that if the source is offset anywhere in the central 3x3 spaxels, and as long as the POC task could measure the offset, the POC result is as good as or better than the SPG result. However, bear in mind that for offsets of > 1 spaxel – which places the source very close to the edge of the 3x3 box – the point-source calibrated spectrum will always suffer a flux loss, no matter which pipeline script was used to produce the spectrum. This is understandable when you consider that the point-source corrections are based on the relationship between the amount of the flux that falls in the central spaxel/central 3x3 spaxels, compared to the total flux from the source. The calibration assumes a perfectly-centred, perfect point source, and if either of these are not true, the calibration should be different. It is this "difference" that the POC tasks attempt to correct for, but the tasks do have their limitations: sources located in the outer edges of the 3x3 spaxel box (offsets of a spaxel, i.e. 9″–10″) will

never be as well corrected for as those with offsets of only a few arcsec.

For the POC HPDPs, only c9 and c129 can be used for science, and these two are, in fact, very similar to each other. The main differences are in SNR, and for point sources offset from the centre of a spaxel, possibly in the profiles of unresolved lines. If a point source is offset from the centre of a spaxel in the dispersion direction (the Y-axis on the jitter plots), the spectral lines will develop a *skew* in their profile. For example, if a point source is located between spaxel 2,2 (the centre) and 2,3 (one up in the Y direction), the spectrum taken from spaxel 2,2 will have lines with a skew towards the longer wavelengths (i.e. a line "leans" to the right); for a source located between spaxels 2,2 and 2,1, the skew for the spectrum taken from spaxel 2,2 will be towards the shorter wavelengths. When summing up the spectra of all 9 spaxels of the 3x3, the merged skews will result in the spectral lines having a broader profile than those from the spectrum taken from the central spaxel alone. This will be noticeable when comparing c9 and c129, as the example plots in "Dealing with point sources observed with PACS spectroscopy" show.

5   Glossary

Chop-Nod observing mode: Two ways were provided by PACS to sample the background from an off position. These are explained in the PACS Handbook. The chop-nod mode was the most used because it produced data with a better continuum reliability and slightly better SNR. In this mode the telescope chopped between an on-source and off-source location at two nod positions.

HSA: Herschel Science Archive

HIPE: Herschel Interactive Processing Environment

IFU: Integral field unit. The footprint of the PACS IFU is a 5x5 grid of spaxels

Pointed observing mode: Pointed mode observations were on a single FoV, and the primary science products are re-binned or interpolated cube, and point-source tables.

Re-binned cubes: "Re-binned cubes" are the final fully-calibrated native cubes that are produced by the pipeline: one cube per requested wavelength range and, for mapping observations, per raster position. It is from the re-binned cubes that the mosaic cubes are produced – these mosaic cubes being the end product for most mapping observations and one possible end product for pointed observations. (The re-binned cubes have the 5x5 grid of 9.4″-sized spaxels that is the native sky footprint of the PACS IFU, while the spatial grid of the mosaic cubes depends on the mapping field requested by the observer and the size chosen for the mosaicked spatial pixels.)

SNR: signal to noise ratio

SPG: Standard Product Generator, short-hand for the automatic pipeline run at the HSC for all Herschel observations. The SPG download/products are the "pipeline" products that a user downloads from the HSA after an archive search.

Spatial Pixel/Spaxel: Both are the name given to the pixels of a cube, each of which contains a full spectrum for a small patch of sky. The difference is that *spaxel* usually refers to the pixel of a native cube (for PACS that is the re-binned cube) with an area that is determined only by the instrument (i.e. 9.4″ for PACS); *spatial pixel* refers to the pixel of a mosaic cube, and it can have any size – the ideal size depends on the mosaicking algorithm and the pointing pattern of the observation (how many overlapping spaxels are there in each spatial pixel?)