PACS SED and large range scan AOT release note

PICC-KL-TN-039

Prepared by	Bart Vandenbussche Alessandra Contursi Helmut Feuchtgruber Ulrich Klaas Albrecht Poglitsch Pierre Royer Roland Vavrek	
Approved by		
Authorised by		

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Issue	Date	Description
1.0	15-11-2009	First internal version
1.1	18-01-2010	Public release
1.2	19-01-2010	Added information on maximum flux density / line flux

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1 Introduction

The following PACS spectroscopy AOTs have been released for scheduling of observations:

❑ Range scan / high sampling density for large ranges

❑ Range scan / nyquist sampling density for large ranges

❑ Range scan / SED mode

This note provides a brief summary of the relevant performance parameters of these modes, gives guidelines to adapt AOR parameters in HSPOT to cope with changes in the band definitions and scanning strategy, and describes the status of the datareduction pipeline and calibration for these modes.

2 Sensitivity

a) The line and continuum sensitivities as a function of observing time have been verified in-orbit and are consistent with pre-launch predictions. The sensitivity in PACS deep range scans is identical to PACS chopped line scans, and is illustrated in figure 1 and figure 2. These show the comparison of pre-launch sensitivity predictions as documented in the PACS observers manual to noise determinations on in-orbit line scan observations. Figure 3 shows the continuum RMS as measured from the PACS level-2 pipeline product of an SED scan of planetary nebula NGC6543. This figure suggest a better continuum RMS than documented in the PACS observers manual, but given the limited accuracy of the present pipeline flux conversion the SED and Nyquist sampling sensitivities should be assumed to be as predicted and given by HSPOT.

b) Optimisation of integration ramp length, chopping frequency and grating scanning strategy have lead to a longer duration of a single scan. The observer can therefore reduce the number of scan or nod repetitions to obtain the same observation sensitivity within the allocated observing time (see section 8: Recommendations for HSPOT AOR updates).
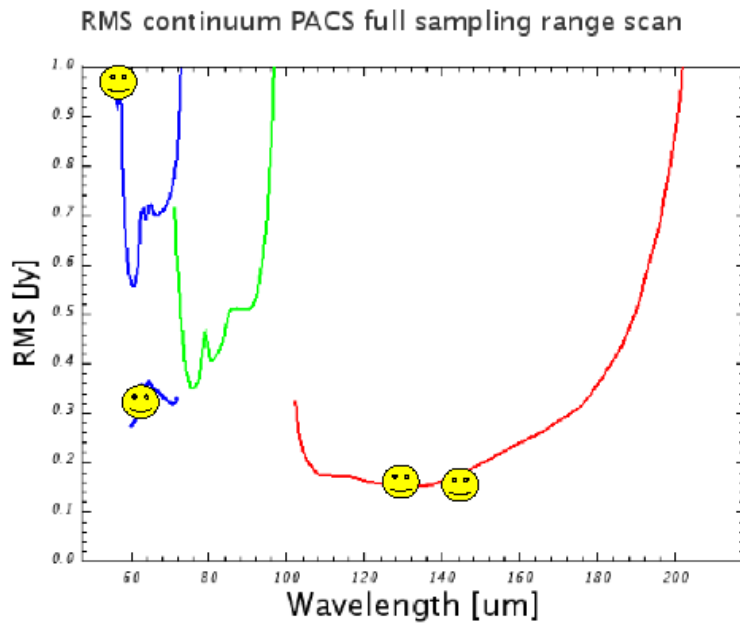
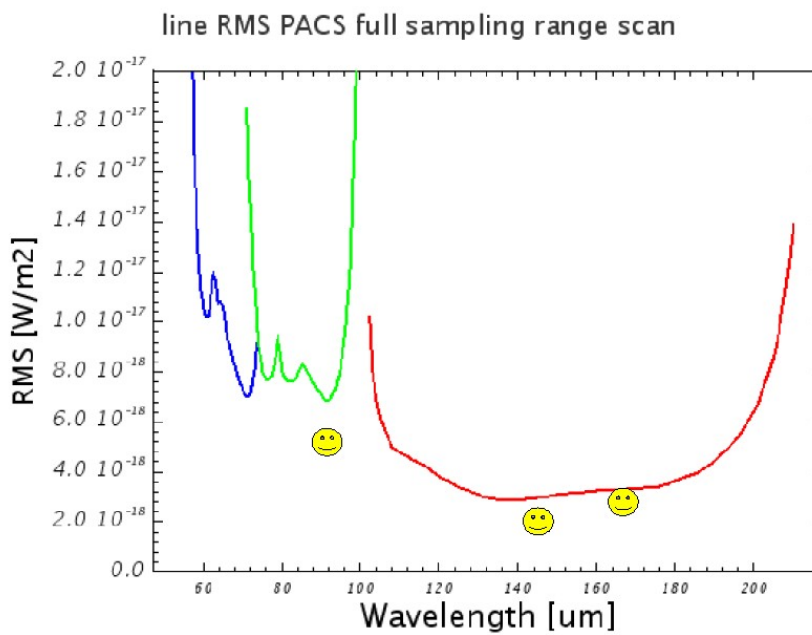*Figure 1: Continuum sensitivity for deep range scans as predicted pre-launch compared to in-orbit spot checks*

Figure 2: Line sensitivity for PACS deep range scans as predicted pre-launch compared to in-orbit spot checks
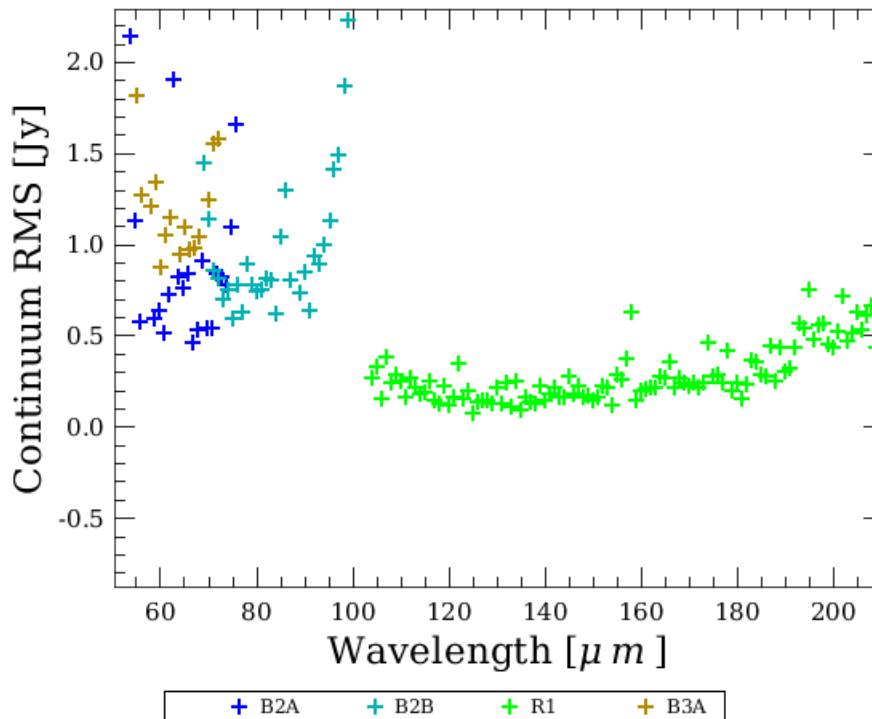
Figure 3: SED (or Niquist sampling) continuum RMS measured from level-2 pipeline product of SED measurement NGC6543. Integration time: 1 hour (bands B2A + B2B + R1) / 0.8 hours (band B3A)

3 Saturation limits

The uplink logic automatic selects the integrating capacitance based on estimated continuum and line fluxes. Figure 4 shows the saturation limit in Jansky for the default integration capacitance. This is the limit for continuum and peak line flux together. Figure 5 shows the default capacitance saturation limits for unresolved lines on a zero continuum. Both figures should allow to judge if the observation can be executed with the default integration capacitance.

If continuum and expected line fluxes are higher than the saturation limits for the default capacitance, it is mandatory to enter the expected continuum and line flux seen in the red channel for every range in HSpot. Observations that are saturated because no HSpot flux estimates were entered by the observer will not be considered as failed for technical reasons. It is the responsibility of the observer to make sure these flux estimates are correctly entered in HSpot.

The estimated line flux and continuum flux estimates need to be entered at the wavelength within the range with the lowest saturation limit. Because of the higher sensitivity of the red spectral chain, this is always in the red band.

Figure 6 and 7 show the saturation limits using the largest integrating capacitance. If the expected line flux and continuum flux are higher than these limits, contact helpdesk to assess the possibility to use non-standard detector settings in an engineering observation.
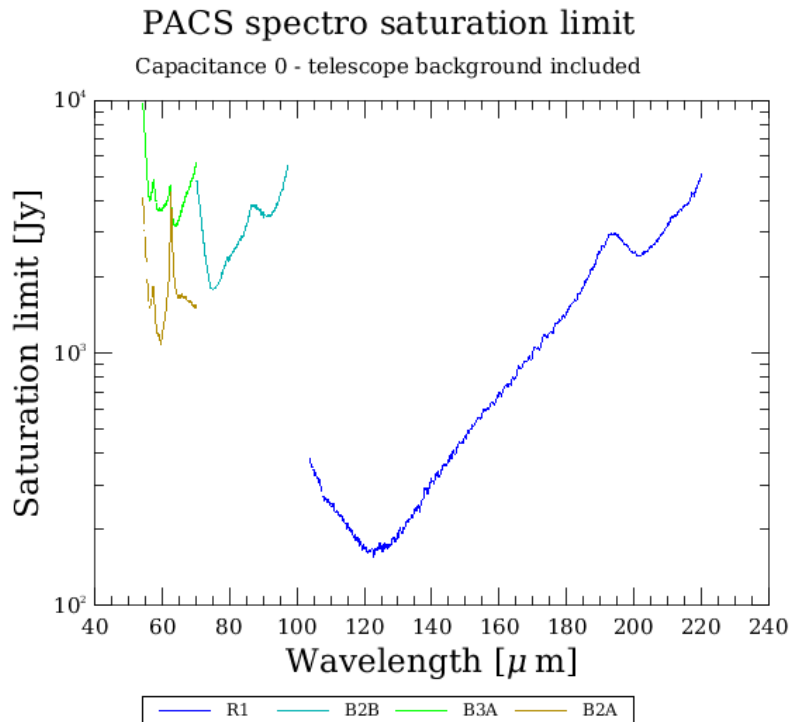
Figure 4: Saturation limit with the (default) smallest integrating capacitance (including 80% safety margin).
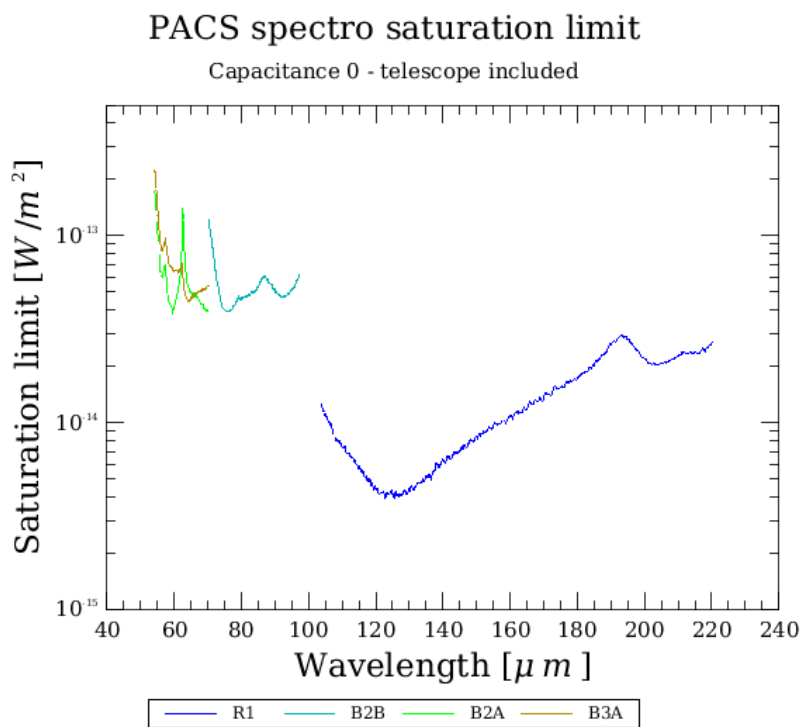

Figure 5: Line flux limit for an unresolved line for the (default) smallest integration capacitance.

PACS spectro saturation limit
Capacitance 12 - telescope background included
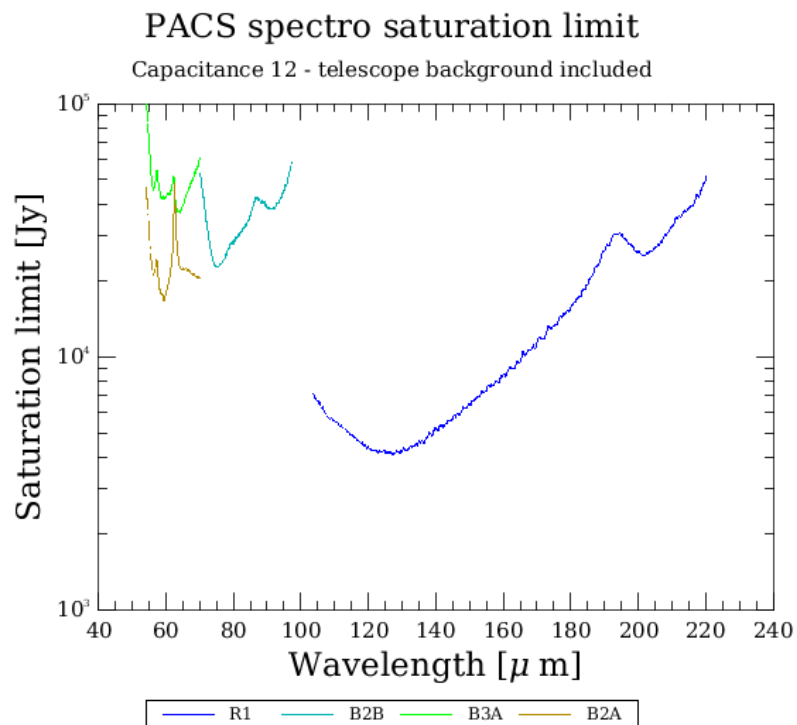
Figure 6: Saturation limit for the largest integrating capacitance.

PACS spectro saturation limit
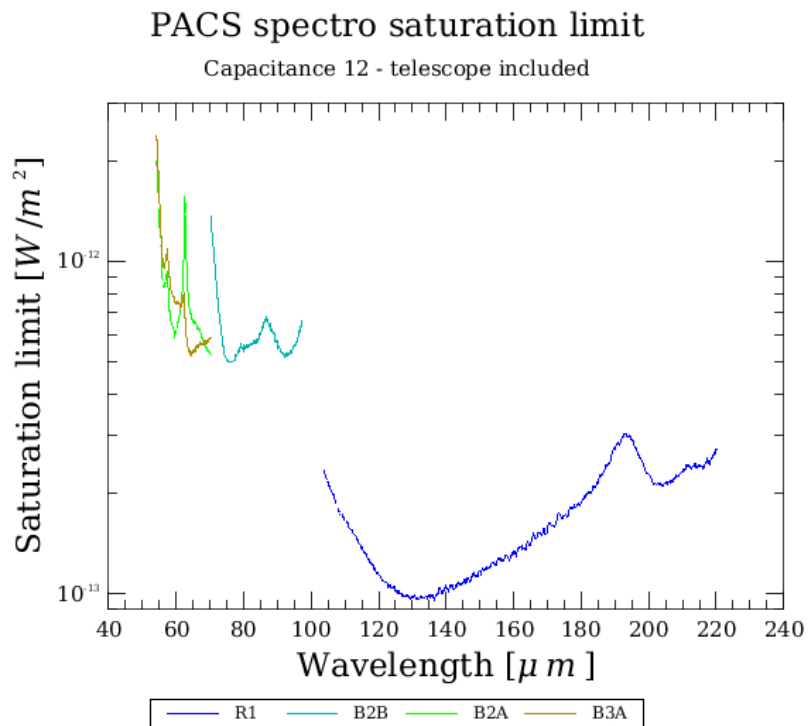### Capacitance 12 - telescope included

Figure 7: Saturation limit for unresolved lines on a zero continuum for the largest integrating capacitance.

4 Spatial and Spectral resolution

The spatial and spectral resolving power have been verified in-orbit and are consistent with the values given in the observers manual.

5 Pointing

The focal plane geometry for the three chopper throws has been established, and the uplink logic parameters have been updated accordingly. The two nod positions center the intended target coordinates to about ~2 arseconds. This has been evaluated to provide the necessary accuracy to combine the spectra obtained at the two nod positions and establish the full power flux calibration for point sources, compensating for differences in the telescope background seen in the two chop positions.

6 Mapping and dithering

The PACS spectrometer "spaxels" of ~9.4"x9.4" size are undersampling the diffraction beam of the Herschel telescope. With several observations (the number depending on wavelength), offset by fractional pixel size steps, the full spatial information can be retrieved. The raster pointing mode is used to generate a suitable set of pointings. Depending on the purpose of the raster map, different raster step sizes are recommended. These strategies are the same as for the line scan or wavelength switching AOTs, and are repeated below.

6.1 Dithering

The dithering scheme of PACS observations offered prior to launch performs a small 1x3 raster with 2" stepsize. For sources with a well known and confined photocenter, the pointing accuracy of Herschel results in reproducibility of line fluxes on the percent level and well behaved line centers and shapes, hence observers can use the simple pointing mode instead, increasing the nod or scan repetitions to maintain the observation integration time needed for the required observation sensitivity.

6.2 Tiling the sky

For raster maps with stepsize >30" (i.e tiling the sky rather than oversampled rasters) there are no particular recommendations for step sizes. Typical step sizes are 47" (no overlap between the different raster positions) and 38" (approximately one row or column of spatial pixels overlap between the different raster positions.

6.3 Nyquist sampling map of extended objects

For extended objects, mapping with oversampling, i.e. with step size smaller than one spaxel, may be very time consuming. Therefore we have tested a mapping strategy with step sizes larger than one spaxel, but such that the beam is nyquist sampled.

Since the PACS Spectrometer projected pixels in the sky are not square, the best recommended step sizes are not equal in Y and Z dimension, (YZ being the spacecraft axes where Y corresponds to the PACS chopping direction) and of course the optimal size changes with the beam size at different wavelengths.

The recommended step sizes (in YZ instrumental coordinates) are:

> BLUE:
>
>> raster step size in z direction = 16.0"
>> raster step size in y direction = 14.5"
>
> RED:
>
>> raster step size in z direction = 24.0"
>> raster step size in y direction = 22.0"

Examples of resulting spaxel pointing patterns are shown in Figure 5. This requires also that maps are commanded as rasters in spacecraft coordinates only. (See also section 9)

6.4 Full PACS spatial resolution Mapping of compact objects

In order to map the sky at full PACS spatial resolution, step sizes smaller than a spaxel have to be used. Since this increases the observing time, this mode is strongly suggested to be used only for mapping almost point-like objects.

In order to recover the best PACS resolution we recommend the following minimum number of raster positions AND maximum step sizes.

> BLUE: 3x3 raster with step size equal to 3.0" in both directions

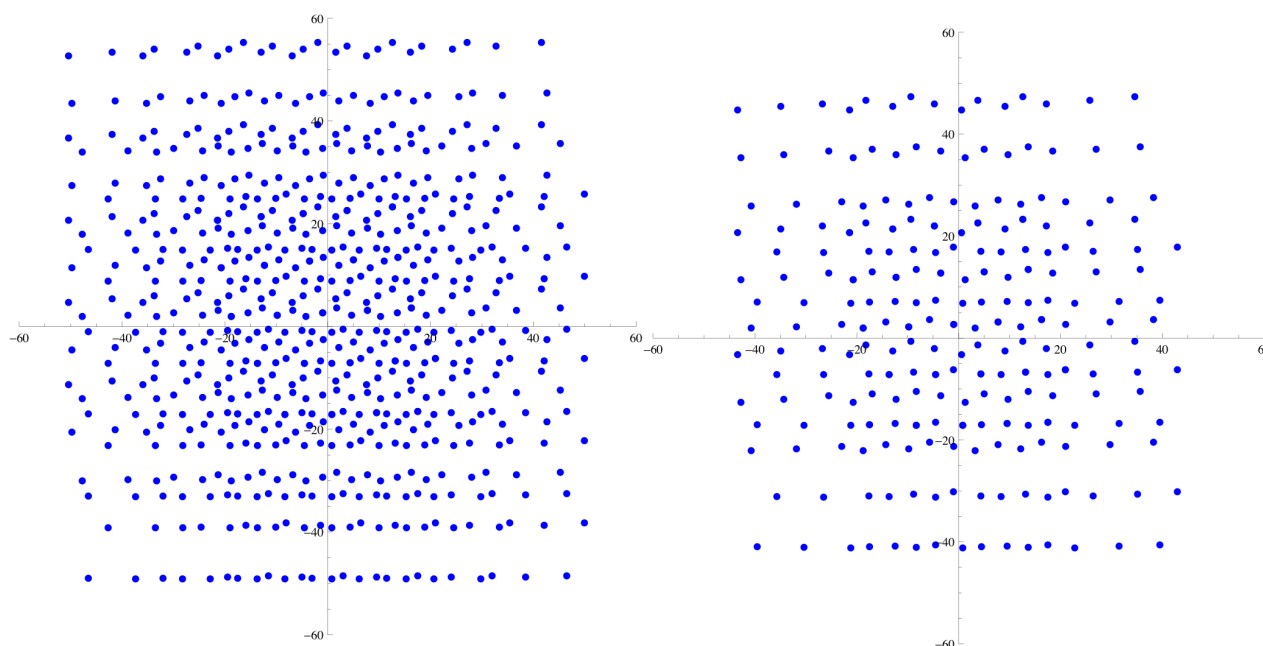> RED:　2x2 raster with step size equal to 4.5" in both directions

Figure 8: Spatial sampling by all PACS spaxels when using a 5x5 raster with step size 14.5"/16" for the blue (left) and a 3x3 raster with step size 22"/24" for the red (right)

7 Calibration and pipeline status

The 2.0 track of the PACS spectrometer pipeline, which is at the moment the operational pipeline at the HSC used to provide the observer with data, provides level1 and level2 data which allows the user to verify the successful execution of the observation. Observations of faint sources might require interactive inspection using the 2.0 track of the Herschel dp system. This will be done routinely at the HSC as part of the quality checks on every observation.

A beta release of the 2.0 track data processing system and a demo of how to process and inspect PACS range scans has been made available to the participants of the Herschel Science Demonstration Phase Data processing workshop. Background presentations, demo scripts and software download instructions are avaible here:

http://herschel.esac.esa.int/SDP_DP_wkshop.shtml

The 2.0 pipeline is still based on ground calibration values. The wavelength calibration accuracy is well within the uncertainties in wavelength imposed by the dependence on source position in the slit.

The ground flux calibration is estimated to be valid for in-orbit conditions to within 50%. Broad spectral features (a few resolution elements) and continuum shape difference of ~20% can be introduced by transient effects and features in the relative spectral response function. Corrections for these effects are under study. In the mean time, such features should not be interpreted blindly. A first check is to compare with the shape of the relative spectral response function at the wavelength where the feature is observed.

Interpretation of spectral features (unresolved or continuum fluxes) in the spectral leakage regions should be avoided without consulting a PACS expert. Figures 9 - 11 show the wavelength regions affected.

The spatial calibration applied in the pipeline is accurate to better than 1 arcsecond; further calibration improvements are expected from in-orbit characterisation of alignment differences of the instrument-level

ground test setup versus the integrated instrument-telescope system.

Updates to these three calibration aspects is well under way, and is expected to be available in the 3.0 track of the herschel dp system by the end of february. The HSC will provide stable beta-versions of the 3.0 track to the observers as the updates to the calibration are validated. The PACS data reduction guide documents well how to reprocess data of the released observation modes from level-0 to rebinned spectra in the individual spaxels, and how the observer can inspect and verify the success of the intermediate processing stages.
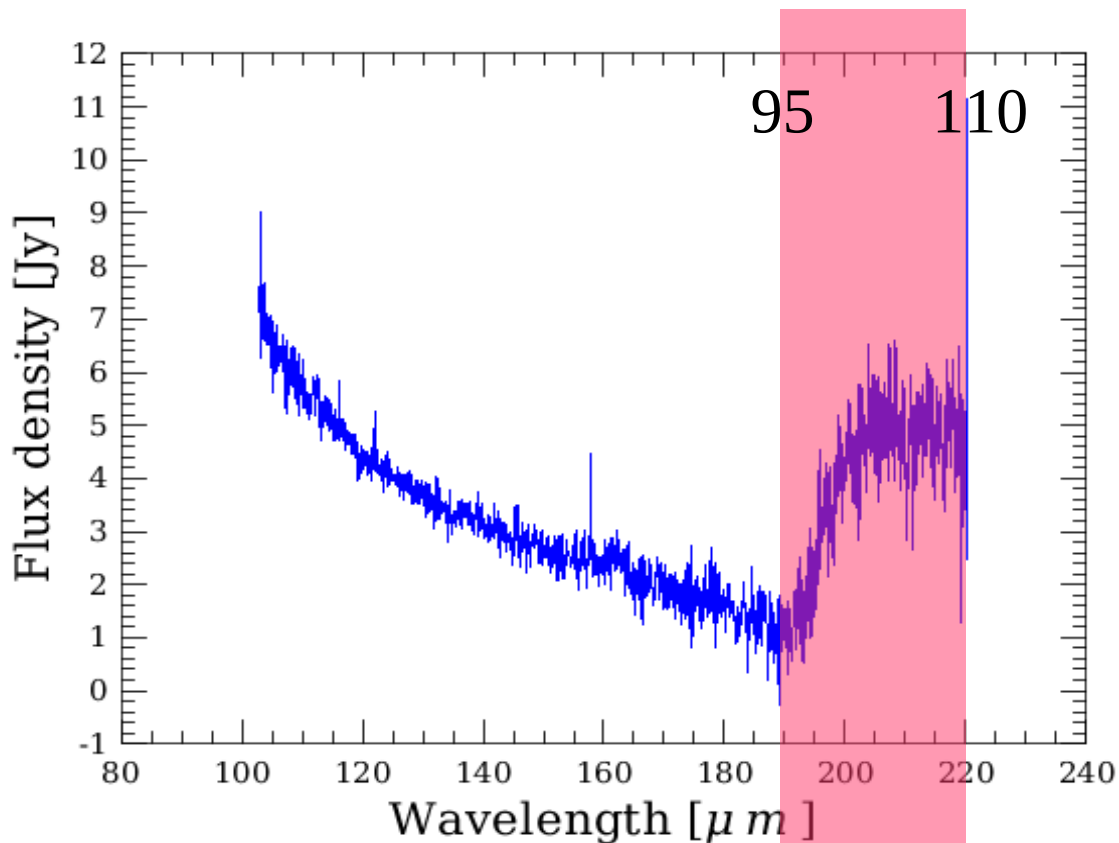

Figure 9: Spectral leakage in band R1: the spectrum between 190-220um has an unreliable (line) flux calibration, and shows superimposed spectral features from order 2 (95-110um).
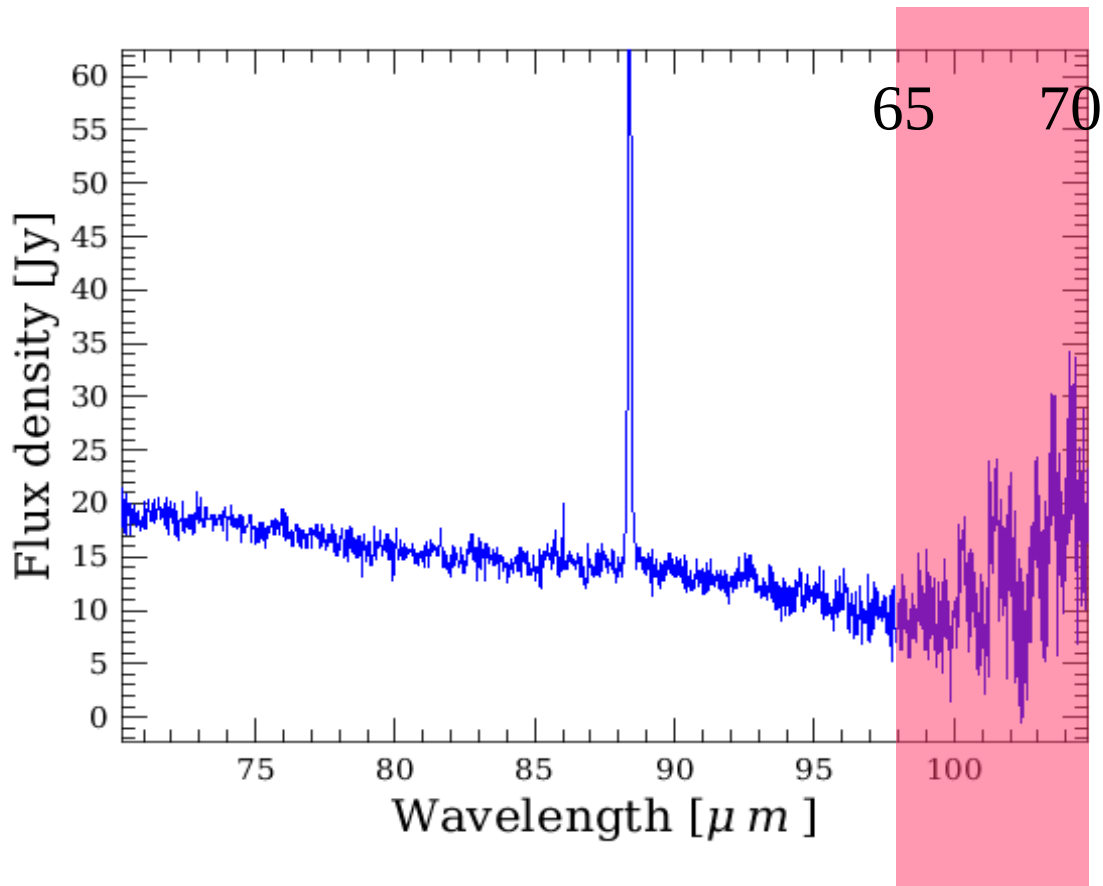
Figure 10: Spectral leakage in band B2B: beyond 98um the response is very low, and spectral features from order 3 (65-70um) are superimposed on the spectrum
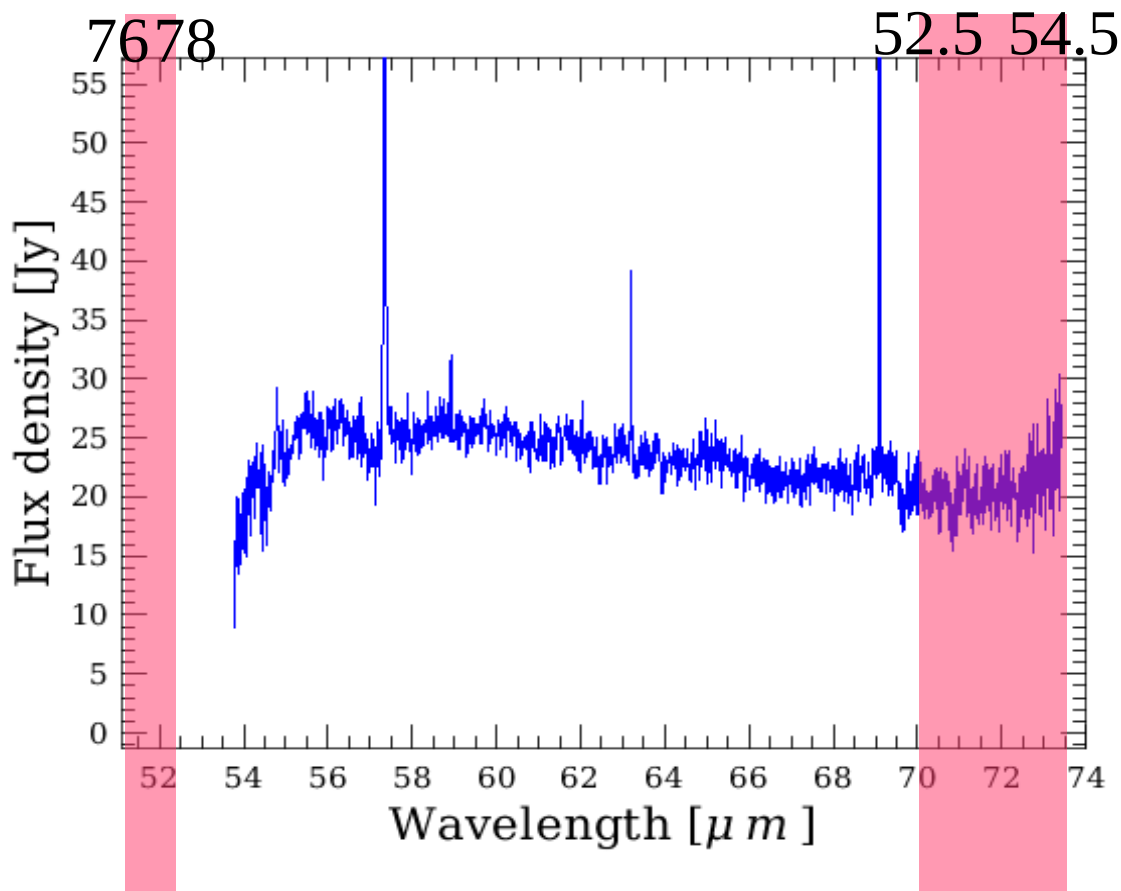
7678 52.5 54.5

Figure 11: Spectral leakage in band B3A: beyond 70um, the order 4 (52,5-54.5um) spectrum is added to the 70-73um order 3 spectrum. The 51-52 order 3 spectrum also shows the 76-78um order 2 spectrum.

8 Recommendations for HSpot AOR updates

- The user interface for entering SED observations in HSPOT has been updated. AORs defined in the old scheme are no longer valid and time estimation is not possible. However, HSPOT can load these AORs to facilitate updating the programme manually.

- A full PACS SED is obtained within 1 hour in order 1 (red detector) and order 2 (blue detector) with two PACS range spectroscopy AORs:

  - AOT A: 1266 seconds - range : SED B2A + short R1: 51-73um + 102 - 146um

  - AOT B: 2344 seconds - range : SED B2B + long R1: 70-105um + 140 - 219um

- For sources where the order 3 spectral resolution is required (see observers manual) e.g. because you look at a source with a rich line spectrum where lines can be blended, an **additional** AOT can be added:

  - AOT C: 2888 seconds – range: SED B3A + long R1: 51-73 um + 153 – 219um

- Deeper observations can be obtained by increasing the repetition factor of the range, and / or increasing the nod repetition factor.

- Full PACS range high sampling scans can be replaced by SED AOTs A, B and C with an

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increased range repetition factor. A spectral dithering scheme is being implemented: the different scans will be performed with a small offset so that one spectral resolution element is seen by as many pixels as possible.

- Range scan / high sampling mode: Scan/nod repetitions should be lowered until the original observing time is maintained.

- Range scans with a single scan / single nod cycle : can be replaced by Nyquist sampled ranges with a repetition factor until the original observing time is maintained. Also here a spectral dithering scheme is being implemented: the different scans will be performed with a small offset so that one spectral resolution element is seen by as many pixels as possible.

- For bright sources where the default integrating capacitance will result in saturation (see section 3) you need to enter the expected continuum flux, line flux and line width at a reference wavelength in the red spectral channel with the highest risk of saturation (see figures in section 3)

   For SED ranges, the reference wavelengths should be the following:

   ○ AOT A: SED B2A + short R1: 51-73um + 102 – 146um : reference wavelength 120um

   ○ AOT B: SED B2B + long R1: 70-105um + 140 – 219um : reference wavelength 145um

   ○ AOT C: SED B3A + long R1: 51-73 um + 153 – 219um : reference wavelength 155um

   For limited ranges specified in band R1 between 102 and 220um: choose the reference wavelength in the covered wavelength range with the highest risk of saturation (see figures in section 3).

   For limited ranges specified in bands B3A (51-73 um) or B2B (70-105um): choose a reference wavelength within the range observed in parallel in the red band.

   The limits of the red range observed in parallel can be calculated as follows:

   band B2B: parallel R1 limits are 2 times the wavelength of the B2B range limits

   band B3A: parallel R1 limits are 3 times the wavelength of the B3A range limits

- Dithering observations: for sources with a well confined photocenter (see section 6), the pointing mode can be changed from 'Pointed with dither' to 'Pointed'. To maintain the observation integration time, nod repetition and/or scan repetitions should be increased until the original observing time is reached. Nod repetition x 3 should be the appropriate change for most observations.

- Raster maps: taking into account that what is defined as raster point step in HSpot corresponds to the spacecraft Z axis, and the line step to the Y axis, the recommended raster step sizes for nyquist sampled maps of larger areas translate to the following HSpot settings:

   ○ Raster in spacecraft coordinates (not fixed on the sky)

   ○ BLUE:
      - point step =16.0"
      - line step =14.5"

   ○ RED:
      - point step =24.0"
      - line step =22.0"

9 Level 2 standard products generated with HCSS v2.0

There are two types of products in the level 2 produced by the pipeline for the PACS spectrometer in range scan mode.

These products are produced by automatic pipeline scripts and shall only be considered as a preview, and not for science directly.

9.1 HPS3DR

HPS3DRB and HPS3DRR stand for "Herschel Pacs Spectroscopy 3D Rebinned" for data in the Blue and Red channels.

This product of *PacsRebinnedCube* type consists nine datasets: `image, ra, dec, qualityControl, noise, exposure, ImageIndex, waveGrid` and `History`. The dataset `'image'` carries the scientific data created by the 'specWaveRebin' pipeline task. This task constructs the lambda x 5 x 5 size IFU cube which is in general the 25 spatial pixels (spaxels) of the PACS spectrometer over the full the depth of the observed wavelength range. Samples from the 16 spectral pixels are rebinned in a grid which is dependent on the actual wavelengths and the oversampling/upsampling factors. The oversample factor is used to increase the number of wavelength bins by the formula bins*oversample, where the number of bins is based on the theoretical resolution of your observation. The upsample factor specifies how many shifts per wavelength bin to make while rebinning. Standard products are generated with oversample=2 and upsample=3 values.

The cube flux values are in Jy/pixel units, the wavelength is in microns. Important notes on flux- and wavelength calibration see above.

In case the observation consists several spectral ranges and/or raster positions then the product is sliced into datasets of logical blocks. Such a a block contains a single spectral range for a single raster position.

9.2 HPS3DP

HPS3DPB and HPS3DPR stand for "Herschel Pacs Spectroscopy 3D Projected" for data in the Blue and Red channels.

This product of *SpectralSimpleCube* type consists four datasets: `image, exposure, ImageIndex` and `History`. The dataset `'image'` carries the scientific data created by the specProject pipeline task. This task projects a rebinned cube (the HPS3DR product) onto a regular RA/Dec grid on the sky. The grid size (corners) are determined by the task using the RA and Dec information from the rebinned cube, the output pixel size (dx,dy) is the default 3 arcseconds for standard products. In this projected cube the number of bins and resolution in the wavelength domain do not change, the cube size is lambda x N x M, where 'N' and 'M' mean the resampled grid size.

In case of mapping observations, 'specProject' loops over all raster positions and combine rasters into a single grid by adding up for each spaxel the fluxes of the contributing spaxels multiplied by their overlap weights.

The cube flux values are in Jy/pixel units, the wavelength is in microns. Important notes on flux- and wavelength calibration see in Section 7.

The HPS3DP product is worth using even for pointed observation because it does not just add together, or mosaic, multiple pointings, but also sets the correct spatial grid for each wavelength of

your cube. For the PACS spectrometer, each wavelength sees a slightly different spatial position, even for spectra within a single spaxel.

In case the observation consists several spectral ranges then the product is sliced into datasets of logical blocks. Such a a block contains a single spectral range combined for all raster positions.