AOT RELATED ASPECTS FOR THE PACS SPECTROMETER

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Contents

1 Purpose of this document

This document provides important material on AOT related aspects for the PACS spectrometer. It focuses mainly on the needs of the ICC with the goals:

1. to provide an overview of the spectrometer hard- and software related aspects, including commanding and band width issues
2. to prepare the ground for the AOT design and discuss the advantages and disadvantages of selected modes and configurations
3. to present the existing AOT concepts
4. to put these concepts into the context of ILT/IST campaigns
5. to identify open topics for the preparation of upcoming ILT/IST campaigns
6. to be used by the simulator, the IA, the commanding and the calibration working groups as reference document and work guideline

2 Reference Documents

RD-01 PACS Science Requirements Document, PACS-ME-RS-004, Issue 1.01, Jan. 2002

RD-02 PACS Instruments Requirements Document, PACS-ME-RS-005, Issue 1, Jan. 2002

RD-03 PACS Instrument Description Document, Part I & II, PACS-ME-GR-002, Issue 2, Jan. 2002

RD-04 Operating Modes of the PACS Instrument, PACS-ME-PL-005, Issue 1.0, Sept 2003

RD-05 PACS Routine Phase Observing Profile, PACS-ME-TN-002, Issue 1.0, Jun. 2000

RD-06 Observation Scenario for the PACS Grating, PACS-ME-TN-014, Issue 1.0, Oct. 2000

RD-07 PACS Grating Assembly Requirement Specification, PACS-ME-RS-009 Issue 1, Jan. 2002

RD-08 PACS OBCPs and DMC Sequences, PACS-ME-LI-005, Issue 1.1, Mar. 2005

RD-09 ISO-SWS: SWS AOT Design Description, Beintema & Kunze, Vers. 1.2, June 1996

RD-10 FIRST Scientific Pointing Modes, PT-SP-04673, Sept. 1997 (Issue 1), Aug. 1999 (Issue 2), update from 01/09/2000 in Annex 4 of the IIDA (SCI-PT-IIDA-04624)

RD-11 DEC/MEC Avionic Model Operating Manual, PACS-CL-OM-001, 9 October 2002, Issue 1.4

RD-12 Design Description for PACS Chopper, PACS-MA-TN-405, Issue 2, 27.11.01

RD-13 Summary of PACS Data Rates, PACS-ME-TN-026, Issue 1, 24-Jan-02

RD-14 PACS Calibration Document, PACS-MA-GS-001, Sept 30, 2003, Draft 7

RD-15 The Photodetector Array Camera & Spectrometer (PACS) for HERSCHEL, Poglitsch, A., Waelkens, C. & Geis, N. 2000, in The Promise of the Herschel Space Observatory, Eds. G.L. Pilbratt, J. Cernicharo, A.M. Heras, T. Prusti & R. Harris. ESA-SP 460, 29

RD-16 DPU OBS User Manual, PACS-CR-UM-024, 11 Jan 2005, Issue 1.8

RD-17 DEC/MEC User Manual For OBS version 5.023, PACS-CL-SR-002, 6 Dec 2004

RD-18 HERSCHEL PACS SPU QM User's Manual, FPL-MA-1214-03-CRS, Version 1, 28 Jan 2005

RD-19 Optical Filter Transmission of the 6 Branches of PACS CQM, PACS-ME-TR-031, 30-06-2004, Draft issue.

RD-20 PACS, Warm Functional Test of QM Detectors after FPU CQM Delivery, PACS-ME-TR-025, Rev. 2, 30.07.2004

RD-21 PACS, Filters and Dichroics Interface Control Document, PACS-ME-ID-004, Issue 2.0, 2003-10-16

RD-22 Herschel/Planck Instrument Interface Document, IID Part A, SCI-PT-IIDA-04624, 30/05/2004, Issue 3.3

RD-23 Herschel/Planck Instrument Interface Document, IID Part B, PACS, SCI-PT-IIDB/PACS-02126, 16/02/2005, Issue 3.3

RD-24 Herschel Pointing accuracy and calibration procedures, SCI-PT-19552, Issue 1, revision 3, 5 Dec 2003

RD-25 Herschel Instrument Scheduling Schemes, Herschel/HSC/DOC/0334, Draft 0.2, 7 July 2003

3 Introduction

Two different observation schemes are currently foreseen for the PACS spectrometer: line and range spectroscopy mode. During the HERSCHEL mission the "normal" PACS user will only specify relevant information from the astronomical point of view (positions, fluxes, key wavelength or range of wavelength, ...) via the HSPOT system. The corresponding satellite and instrument operations have to be selected and set accordingly in an automatic way. The logic behind this process is currently under development. These standardized observing procedures (or astronomical observation templates - AOT) will be associated with user interfaces, which will evolve from cryptic collections of instrument commands during the first instrument level tests to simple, self-explaining AOT interfaces (with a sophisticated logic behind) during the mission. This document describes the many different aspects which have to be considered for the selection of useful instrument configurations, observing modes and calibration procedures.

3.1 Line spectroscopy mode

A limited number of relatively narrow emission/absorption lines can be observed for either a single spectroscopic FOV or for a larger map. Background subtraction can be achieved either through standard chopping/nodding (for faint/compact sources) or through 'frequency-switching' techniques (for line measurements of bright extended sources) of the grating mechanism. Note: The frequency switch mode eliminates the source continuum information!

The fixed wavelength and its immediate neighborhood (as defined by the instantaneous bandwidth of the spectrometer) is observed for each chopper and grating position. For improved flat-fielding, especially for long integrations, the grating will be scanned by a number of discrete steps around a specified centre position such that drifts in detector responsivity between individual pixels are eliminated. The scanning will be synchronised with the chopper which is foreseen for the majority of the observations.

Depending on the requested wavelength/grating order, only the data of one of the two detector arrays is normally of interest to the observer.

3.2 Range spectroscopy mode

A freely defined wavelength range (limited only by the grating order boundaries) will be scanned by stepping through the respective angles, synchronized with the chopper. Both arrays will be used at a time. The specified wavelength ranges will be scanned by default at full spectral resolution. Optionally, scans can be made at decreased resolution (faster speed). Low resolution spectra can be obtained by stepping the grating for example at angles corresponding to the size of the instantaneous spectral coverage of one spatial pixel (the 1x16 detector pixel column per spatial pixel covers roughly 1500 km/s corresponding to a spectral resolution of about 200), but depending on the required redundancy, smaller or larger steps can be choosen.

3.3 Spectrometer operations

The following pointing modes are relevant for spectroscopy: Staring, raster with/without off position, position switching (on/off positions through telescope repointing, special raster), nodding, SSO tracking (for a detailed description of these modes see RD-10).

A reference flux for the determination of the actual detector responsivity will be provided by regular switching to the PACS calibration sources. Additional calibration measurements will be done at the beginning and the end of an operational day and before and after an AOT observation. Some of these calibration measurements will be performed during slew times in order to use the on-target time in the most efficient way.

Most likely, only one PACS sub-instrument will be used during one operational day of 24 hours (here: 21 hours of PACS spectroscopy and 3 hours of daily telecommunication period DTCP, see also RD-05). The typical duration for switching on and setting up the instrument for spectroscopy is about 45 min, mainly due to the long stabilisation time for the PACS internal calibration sources (could be done during the DTCP of the previous observing day). Additionally, detector curing might be necessary at the beginning of a PACS spectrometer observing period (TBC).

In spectroscopy mode both detector arrays will produce valid data in parallel and view the same FOV. For the blue array the observer has to select either second or third order data (through setting of the corresponding order sorting filter), while the red array always takes data in first order. Especially in line spectroscopy mode the observer is usually not interested in these parallel data. For some wavelength ranges the parallel data are even outside the nominal range (see Tbl. 3 or Fig. 21). To save bandwidth in the data downlink these parallel data might be deselected (see Sect. 5.5).

4 PACS Spectrometer Instrument Aspects

4.1 General Aspects

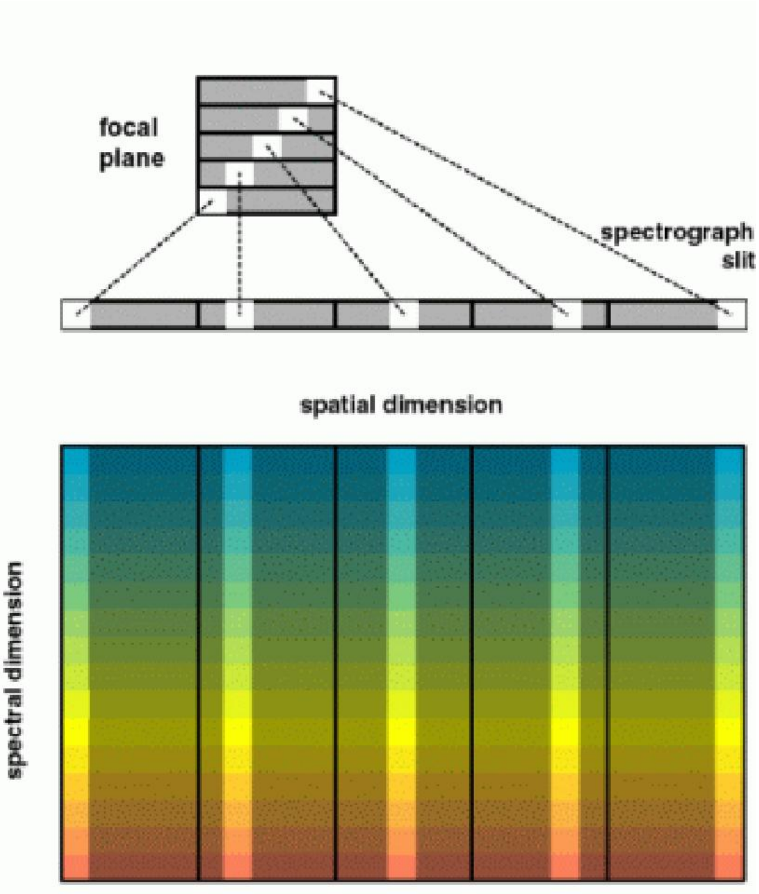

Figure 1: Projection of focal plane onto the detector (spectroscopy mode).

RD-03, RD-15: The PACS Integral-Field Spectrometer covers the three wavelength bands from 55-72, 72-105 and 105-210 μm with an effective resolution of $\lambda/\Delta\lambda$ of 6000 to 1000 or $c\Delta\lambda/\lambda$ equals 50 to 300 km/s, depending on wavelength and order (see Sect. 4.3). A sky field of $47\times47\,\mathrm{arcsec}^2$ is simultaneously imaged and resolved into 5×5 pixels (each pixel has a size of 9.4 arcsec). This integral-field concept has been selected because simultaneous spectral and spatial multiplexing allows the most efficient detection of weak individual spectal lines with sufficient baseline coverage and high tolerance to pointing errors without compromising spatial resolution, as well as for spectral line mapping of extended sources regardless of their intrinsic velocity structure. The spectrometer optical train includes an image slicer unit for integral field spectroscopy, an anamorphic collimator, a diffraction grating in Littrow mount with associated actuator and position readout, anamorphic re-imaging optics, and a dichroic beam splitter for separation of diffraction orders. The image slicer is used to re-arrange the field of view along the 1×25 pixels entrance slit of the PACS grating spectrometer (see Fig. 1). The anamorphic collimating optics expands the beam to an elliptical cross section to illuminate the grating over a length required to reach the desired spectral resolution. The dichroic beam splitter separates the light from the first diffraction order vs. light from the other two orders. Anamorphic re-imaging optics is employed to independently match the spatial and spectral resolution of the system to the square pixels of the detector arrays.

The spectrometer contains 2 photoconductor arrays with attached cryogenic read-out electronics (CRE). For spectroscopy (as for photometry) background-noise limited performance is expected, with a sensitivity of $2 - 8 \times 10^{-18}\,Wm^{-2}$ (5σ in 1 h).

4.2 Chopper

4.2.1 Description

The PACS chopper assembly (Fig. 3) is a sub-system of the HERSCHEL-PACS focal plane unit. It consists of:

- a 26×32 mm size mirror connected to a flexible pivot
- position and temperature sensors
- housing with I/F point
- pigtail with I/F connector

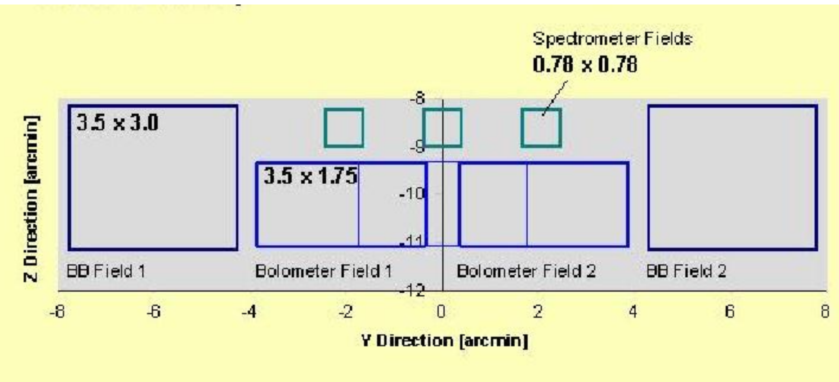

Figure 2: PACS FOV on the sky.

4.2.2 Commanding

The relation between field-plate (position sensor) output voltage and the chopper deflection has been (CQM)/ will be (FM) established during module level tests at Zeiss (see also Appendix E). This relation is non-linear and not fully symmetric with regard to the zero point. In their electrical equipment Zeiss applied an amplification factor of 34.35 to the field-plate output voltage. The relations are shown in Fig. 4 for both field plates. Note that FP1 and FP2 have zero point offsets in voltage of $\approx$ -0.357 V and $\approx$ +0.376 V, respectively.

4.2.3 Performance

The DECMEC uses an amplification factor of ≈ 50 (will be more accurately specified in future versions). An output voltage of ±10 V corresponds to a read-out value of $\mathrm{RO}_{\mathrm{DMC}} = \pm 32\,767$. Read-out values during CQM tests refer to field plate 1. In order to compensate for the zero point offset in voltage an offset value of 2073 read-out units has been applied.

For the assignment of an angle to a read-out unit, the following relation applies:

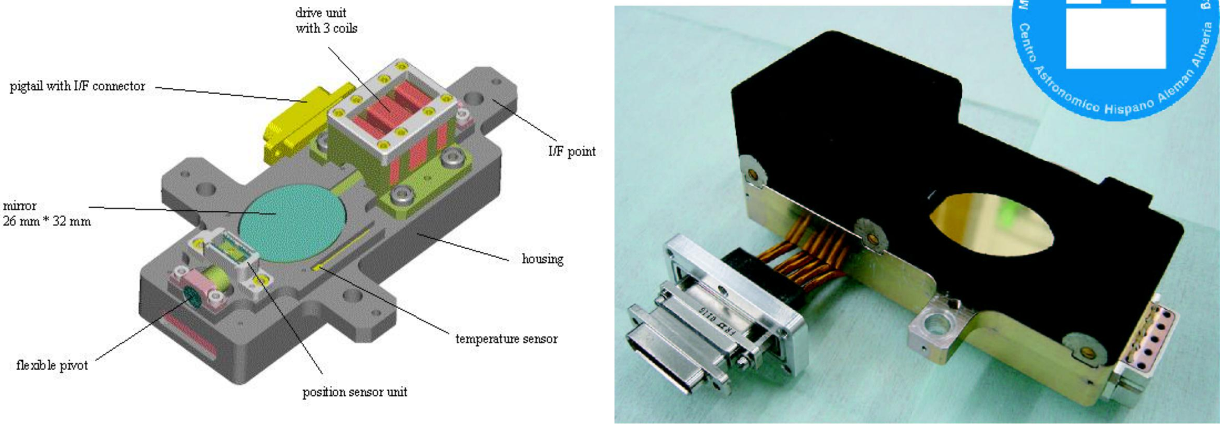

Figure 3: The PACS chopper is used for sky modulation and also to deflect the detector field of view toward 2 internal calibration sources. Left: A schematic view of the PACS chopper. Right: Qualification Model of the focal plane chopper.

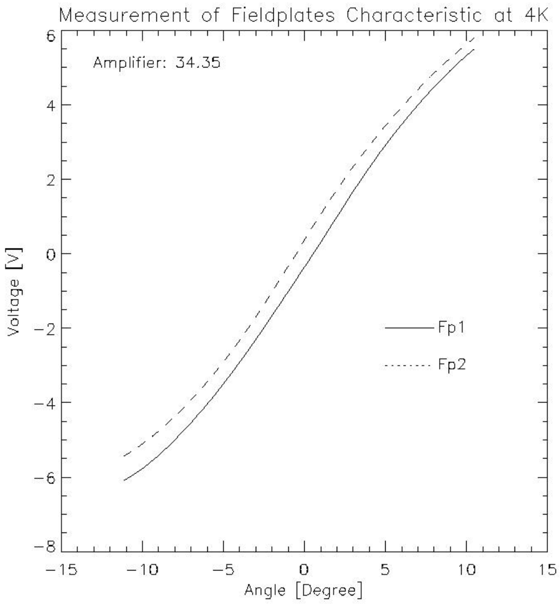

Figure 4: Angular calibration (CQM) of both field plate output voltages by Zeiss.

$$V_{\mathrm{Zeiss}} = \frac{34.35}{50} \times \frac{10\,V}{32767} \times (RO_{\mathrm{DMC}} - 2073)$$

Table 1: Conversion table for the PACS chopper. The relative sky position refers to the central point (pixel) in the FOV.

Chopper FOV	chopper deflection [deg]	relative sky position [arcmin]	commanding units[3]
Mechanical stop:	≈-16.00[1]	n/a	n/a
Electrical range goes to:	≈-9.67[2]	-7.08	-26 105
PACS Calibration Source 1 (edge):	-9.00	-6.59	-25 155
PACS Calibration Source 1 (center):	-7.85	-5.74	-22 605
Spectrometer Science window:	-4.10 ... +4.10	-3.00...+3.00	-12 704 ... +14 111
Optimal sky position:	-2.38	-1.74	-5 300
Chopper null position:	0.00	0.00	+390
Optimal sky position:	+2.38	+1.74	+6 259
PACS Calibration Source 2 (center):	+7.85	+5.74	+24 162
PACS Calibration Source 2 (edge):	+9.00	+6.59	+26 919
Electrical range goes to:	≈+9.24[2]	+6.76	+27 263
Mechanical stop:	≈+16.00[1]	n/a	n/a

[1] determined by maximum deflection of flexural pivots

[2] for CQM determined by maximum coil current (41.667 mA) – coil current will be increased to 100 mA for FM

[3] the commanding units refer to the chopper target, to get the field-plate read-out units a factor of 0.95 has to be applied. The numbers refer to field-plate 1 output.

With $\mathrm{V_{Zeiss}}$ the table in the appendix can be used to derive the deflection angle. For the commanding it has to be noted that the ratio between $\mathrm{RO_{DMC}}$ and $\mathrm{TARG_{DMC}}$ is $\frac{RO_{\mathrm{DMC}}}{TARG_{\mathrm{DMC}}} = 0.95$.

A chopper tilt of 1 deg corresponds to 1/82 deg (= 43.9 arcsec) on the sky. A beam separation of 3 arcmin requires therefore a chopper throw of 4.1 deg (see Y direction scale in Fig. 2). The spectrometer 5×5 pixel FOV is about 47×47 arcsec^2 (about 0.78×0.78 arcmin^2). Therefore, on-off separations ranging from about 0.8 arcmin to about 6 arcmin on the sky will be possible. Typical sky position chopping might be done with chopper amplitudes of ±2.38 deg corresponding to about 3.5 arcmin separation on the sky. Smaller amplitudes would lower the signal differences due to temperature gradients on the telescope mirror and minimise distortions, larger amplitudes might be required for extended objects. On-array chopping will most likely not be practical. The relatively small PSF separation in the 5×5 FOV together with the observing day dependent chopper angle on the sky will restrict this concept to rare cases where clean on- and off-positions could be placed in opposite corners of the 5×5 pixel FOV (see Fig. 1). If no clean off-position is reachable with the chopper (the maximal amplitude within the science window is about $6'$), then frequency switching is required to determine the background level. Table 1 summarizes the full range of possible chopper deflections together with sky positions and commanding units.

It is also possible to perform a predefined chopper pattern (dithering). Currently, a random pattern of 128 positions is coded in a DMC table (128 random chopper commanding unit numbers, which can be modified by a scaling factor through a specific DMC command). Since on-array chopping is hardly possible (see above), on-array dithering for improved flat-fielding will also be impractical in spectroscopy mode. Additionally, a full dither pattern per grating position is very time consuming and moving the grating during dithering might produce data which are very difficult to analyse. But the dithering concept might still be useful in cases where several chopper positions (e.g. more than 2 off-positions) are required for a better background subtraction or higher spatial resolution, but adjusting the positions currently requires a DMC software change (simple position uploading is not possible).

4.3 Grating

4.3.1 Description

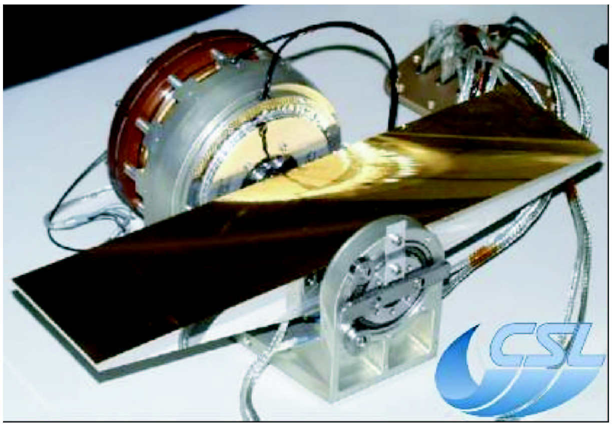

Figure 5: Qualification Model of the grating unit. A torquer motor is used to actuate the grating angle which is measured with sub-arcsecond precision by an Inductosyn angular resolver.

The PACS-Grating Assembly is a sub-system of the HERSCHEL-PACS focal plane unit. It consists of a Littrow-mounted grating blank with a size of $320 \times 80\,\mathrm{mm}^2$, a mounting bracket that interfaces with the FPU structure, the actuator with redundant coils that provides for positioning of the grating, the redundant position sensors, a launch lock mechanism with redundant coils for the launch-lock actuator, the redundant temperature sensors and the duplicated cryo-harness (see Fig. 5). The grating is actuated by a cryogenic motor with a resolution better than 1 arcsec which allows spectral scaning/stepping for improved spectral flatfielding and for coverage of extended wavelength ranges.

The grating blank has a length of 320 mm with a groove period of 8.50±0.05 grooves/mm (in total approx. 2720 grooves). At longer wavelengths, the diffraction-limited footprint of the beam on the grating blank is much larger than the geometrical footprint (see Fig. 27 for the geometrical footprint and IIDR presentation by N. Geis, p. 113/114 for the diffraction-limited footprint). The facet angles of the grating are: left facet angle: 62.44 deg, right facet angle: 34.5 deg. The groove depth is $56\,\mu$m, the ridge width is $4\,\mu$m. There is a small deviation from perfect Littrow mount of 1.12 deg (this has so far not been taken into account for the grating angle – wavelength relations in Tbl. 3 or Fig. 21). This offset will improve the situation in the short wavelength range in first order which is currently outside the allowed grating angle range (see Fig. 21 based on simplified calculations), but detailed calculations still have to be done.

The reflection grating is operated in the 1^{st} (210-105 μm), the 2^{nd} (105-72 μm) and the 3^{rd} diffraction order (72-55 μm). Grating deflections from 28 deg to 68 deg are possible to cover the full wavelength range in each order. A graphical correlation of the grating angle of incidence vs. order and wavelength is given in Fig. 21 in the appendix or in Fig. 6.2-10, page 6-15 in RD-03. The spectrometer resolution vs. wavelength and order is given in Fig. 25 of the appendix or in Fig. 6.2-13, page 6-19 in RD-03.

An effective resolution of $\lambda/\Delta\lambda \sim 5500 - 940$ ($c\Delta\lambda/\lambda \sim 55 - 320\,\mathrm{km/s}$) can be obtained. The instantaneous 16 pixel spectral coverage is $\sim 500 - 100$ ($600 - 2900\,\mathrm{km/s}$), corresponding to $\sim 0.15 - 1.00\,\mu$m wavelength coverage. Table 2 summarises the grating characterisation in terms of velocity resolution, spectral coverage and typical grating step sizes for a given order/wavelength. The effective resolution (expressed in FWHM of unresolved line) was calculated by the geometric sum of the intrinsic resolution of the grating spectrum as projected onto the detector array and the detector pixel size (see also Fig. 25). These numbers should be representative for our goal of AOT design stuides. A more accurate calculation of the PACS effective resolution would have to take into account the convolution of the spectral point spread function and the pixel size, considering also the non-uniform illumination of the grating due to diffraction effects in the slicer. The corresponding formulae and graphical representation can be seen in the appendix B.

Table 2: PACS grating/pixel spectral characterisation.

n	λ [μm]	grating angle [deg]	FWHM [km/s]	FWHM [μm]	16 pix coverage [km/s]	16 pix coverage [μm]	pixel per FWHM	grating deflection for step sizes of 1/5 FWHM	grating deflection for step sizes of 3 FWHM	grating deflection for step sizes of 16 pixels
1	105	26.50	318	0.111	2856	1.000	1.78	$22''$	$5.5'$	$16.3'$
1	158	42.18	239	0.126	1572	0.828	2.43	$30''$	$7.4'$	$16.3'$
1	175	48.05	212	0.124	1280	0.747	2.65	$32''$	$8.1'$	$16.3'$
1	210	63.19	140	0.098	720	0.504	3.11	$38''$	$9.4'$	$16.2'$
2	72	37.73	164	0.039	1840	0.442	1.42	$17''$	$4.4'$	$16.4'$
2	105	63.19	80	0.028	720	0.252	1.78	$21''$	$5.4'$	$16.0'$
3	55	44.53	114	0.021	1448	0.266	1.26	$16''$	$3.9'$	$16.5'$
3	72	66.63	55	0.013	615	0.148	1.42	$17''$	$4.2'$	$15.8'$

4.3.2 Commanding

A preliminary conversion between grating angle (λ), commanded grating position units and wavelengths (precise numbers TBC) are given in Table 3: 2^{23} units = 8 388 608 → 360 deg; 1 deg = 23 301 units; $1' =$ 388 units; $1'' =$ 6.5 units (RD-17). A dichroic beam splitter separates the first (red detector) from second and third order (blue detector). Two order sorting filters mounted on an additional filter wheel separate second from third order (see Sect. 4.4).

For range spectroscopy, the grating moves over large parts of its full available range. In line spectroscopy mode and for reference measurements on the PACS internal calibration sources, the grating moves around certain angles corresponding to a few key wavelengths. This means that the potential mechanical wear of the grating drive is not distributed evenly. Frequent usage of the frequency switching mode will add to the uneven mechanical wear of the grating.
Note: Unnecessary grating movement should be avoided to optimise observing time and to reduce heat load from the grating controller/drive.

Table 3: Conversion table for the PACS grating. Note: The approximate commanding units are only valid for the STM and QM grating models where the inductosyn is mounted in reverse position.

relative angle deg]	absolute angle [deg]	approx. commanding units	λ in 1^{st} order [μm]	λ in 2^{nd} order [μm]	λ in 3^{rd} order [μm]
outside	26.50	960 000	105.0	—	—
-20.00	28.00	920 000	110.5	—	—
-10.27	37.73	695 000	144.0	72.0	—
-5.82	42.18	590 000	158.0	79.0	—
-3.47	44.53	535 000	165.0	82.5	55.0
0.00	48.00	454 000	174.9	87.4	58.3
+0.05	48.05	453 000	175.0	87.5	58.3
+15.19	63.19	95 000	210.0	105.0	70.0
+18.63	66.63	15 000	—	—	72.0
+20.00	68.00	0	—	—	—

4.3.3 Grating Speed

Currently, the grating speed is fixed at $\sim$ 1.05°/second by the grating controller "rate" parameter, independent of the amplitude of the movement. The "rate" parameter can be modified to reach the required 4°/second without changing the controller PID parameters and with negligible energetic and mechanical impact, but so far this was not tested. The stabilisation time, which is negligible in the case of large amplitude movements, becomes significant for small movements. During the CQM tests, the grating transition time was found to obey $t \leq 0.032 \cdot 116.505/23301$ for amplitudes $\lesssim$ 1.5 arcmin (650 units). For bigger amplitudes, 1.05°/second is a good approximation (see Fig. 6). This impacts

- the movements of the grating over the entire range. Ideally performed in < 10 seconds (corresponding to 4°/second), they actually take about 40 seconds.

- the wavelength switching. RD-07 specifies that it should be possible at 3 Hz with a duty cycle of 80% for amplitudes smaller than 3 arcmin. This would require a grating speed of 1.5°/sec (a total movement of 18 arcmin to be operated in 0.2 second). So far, this was not reached. In practise, the requirement for frequency switching should be that grating deflections of 3 FWHM are possible with frequencies of 3 Hz and a duty cycle of 80 %, corresponding to $3.9' \ldots 9.4'$ grating deflections (see Tbl. 2). This would lead to an average grating speed of up to 5 deg/sec ($6 \cdot 9.4'$ in 0.2 sec). This value would then be even larger than the original 4 deg/sec requirement.

From the commanding point of view, the following translation for the grating speed can be used (observed transition times + $3\,\sigma$): 0 units $\cong$ 0 sec, 657 units $\cong$ 0.18 sec and 1 500 000 $\cong$ 6.131 sec.

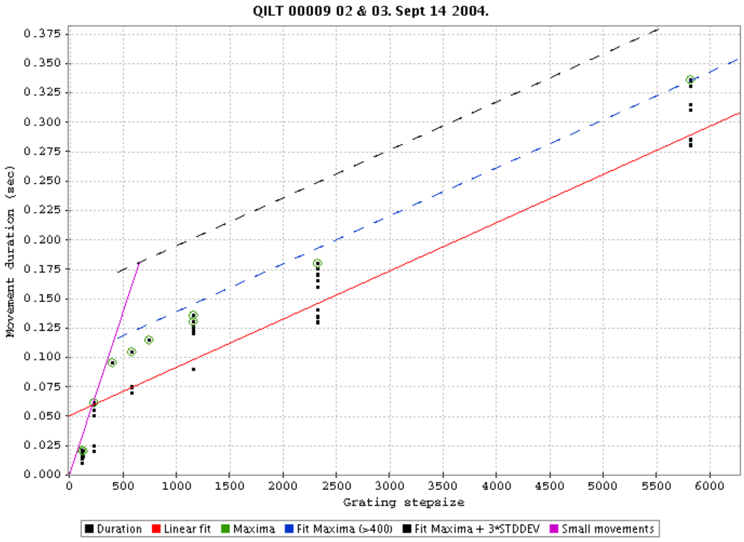

Figure 6: Grating transition times. The black dots are measurements, the red curve is a fit to them. The measurements kept for defining the "calibration table" are marked by green circles. The fit to those measurements is shown in blue. The fit+$3 \times \sigma$ is shown in black. The purple line is the relation for small grating movements. On this figure, all movements seem well shorter than the dashed black line, but it is worth noting that, some of the slightly bigger movements (not shown here, e.g. for 1°, 23301 units) nearly reach that line.

4.3.4 Key Features

- first order data are always taken (red detector; 210-105 μm; 63.2 - 26.5 deg grating angle) For line scans in second or third order one might deselect the first order data to lower the data transmission rates.
- second or third order spectra are taken simultaneously with first order data in the blue detector (by selecting the corresponding order sorting filter). Second order covers the range 105- 72 μm (63.2 - 37.7 deg grating angle), third order covers 72- 55 μm (66.6 - 44.5 deg). For line scans in first order one might deselect the second/third order data to lower the data transmission rates.
- smallest grating step size equals $3''$ $\rightarrow$ 48 000 steps for the full 40 deg grating range from about 28 to 68 deg!
- typical step sizes during nominal observations will be between 15 and about 40 arcsec to obtain 1/5 FWHM resolution.
- reduced resolution scans can either be done via the "fast full spectral scan" (see corresponding AOT section) or via multiple short line scans distributed over the full PACS wavelength (this would be a kind of SED mode). The fast AOT mode provides a Nyquist spectral sampling over the entire wavelength range, using a step size of about 2500.

- for frequency switching the grating has to be rotated by 4 to 10 arcmin to have a displacement of 3 FWHM resolution elements (see Table 2)

4.4 Filter

The PACS filters, in combination with the detectors, define the wavelength bands of the instruments. There are in total 3 bands in the PACS spectrometer: 57-72 μm, 72-105 μm and 105-210 μm [RD-19]. The transmission and reflection measurements have been performed in cold conditions near 4.2 K with a resolution of 0.5 cm^{-1} in the wavelength range between 2.5 and 500 μm. Only the dichroic D_S_1 in reflection has only been measured at room temperatures. Other optical components, like the grating or various mirrors, have not been considered. Within the bands a flat detector response has been assumed for the in-band transmission efficiency.

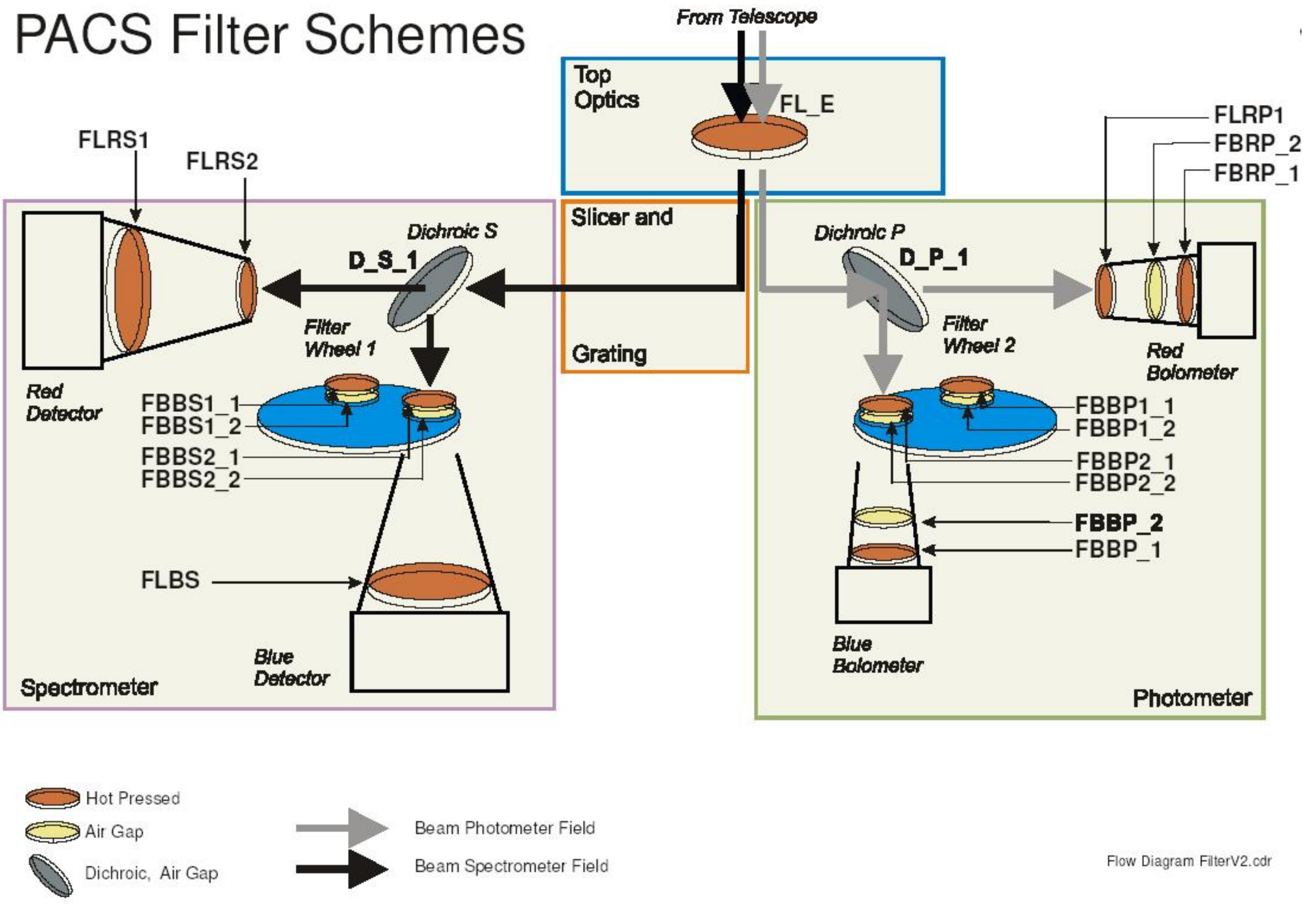

Figure 7: The PACS filter scheme gives an overview over the location and the type of the filters/dichroics in PACS, its optical beam path and the respective ID number of the individual filters/dichroics.

Figure 7 gives on overview over the filter arrangements in PACS. Further details are given in [RD-21]. The selection of the blue spectrometer filter is done via commanding of the filter wheel #1: switch-on of the spectrometer filter wheel controller (this will switch-off the grating controller and the photometer filter wheel controller), move the filter wheel to position 0 (blue channel, short wavelength band, TBC) or to position 1 (blue channel, long wavelength band, TBC) and switch-off the controller.

Note: The filter wheel controller is applying a current in the motor only during a move. Once the wheel has reached the requested position, the current is set to zero. So, if the filter wheel is not retained by a magnet, it might move even if not requested. A typical filter change takes about 12 sec (at least for the photometer filter wheel) which is covered in the conservative wait times of 15 sec in the commanding sequences.

4.4.1 Red Spectrometer Band 105-210 μm

The filter chain for the red spectrometer branch consists of 4 individual filters: F_L_E, located in the top optics, D_S_1 (transmission at an angle of 20°), which is part of the blue/red spectrometer optics, FLRS1 and FLRS2, which are part of the red spectrometer. The transmission values are 0.28% at 105 μm, $\sim$ 70% in the region 125 to 150 μm and 54% at 210 μm (see Fig. 8). There is no blocking at long wavelengths and a out-of-band suppression of 5.0×10^{-7} at short wavelengths. The in-band transmission efficiency is 61%.

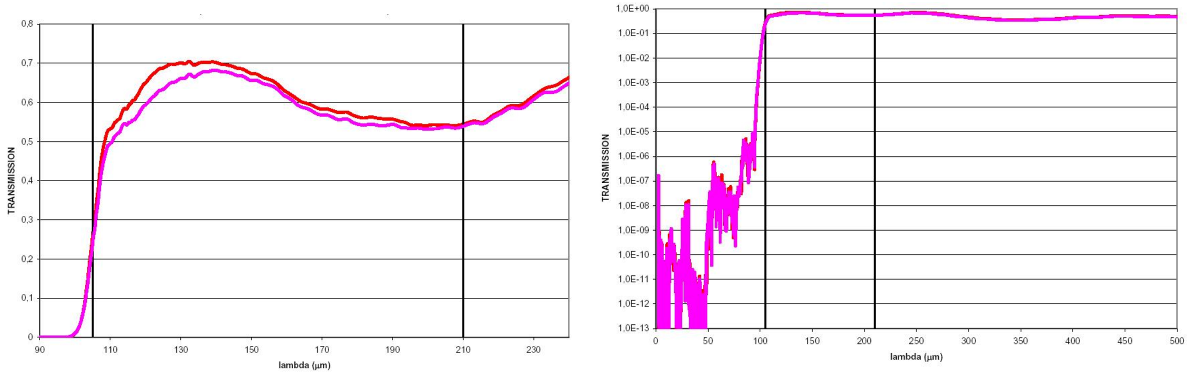

Figure 8: Red spectrometer band 105-210 μm. The red line corresponds to the FLRS1 filter B703, the pink line to the FLRS1 filter B706.

4.4.2 Blue Spectrometer Band 57-72 μm

The filter chain for the short wavelength branch of the blue spectrometer consists of the filters: F_L_E, located in the top optics, D_S_1 (reflection at an angle of 20°), which is part of the blue/red spectrometer optics, FLBS (part of the blue spectrometer) and FBBS1, located at the spectrometer filter wheel. The transmission values are 0.29% at 57 μm, $\sim$ 60% around 63 μm and 30% at 72 μm (see Fig. 9). The out-of-band suppression at short wavelengths is lower than 10^{-5} and at long wavelenghts lower than 10^{-4}. The in-band transmission efficiency is 44%.

4.4.3 Blue Spectrometer Band 72-110 μm

The filter chain for the long wavelength branch of the blue spectrometer consists of the filters: F_L_E, located in the top optics, D_S_1 (reflection at an angle of 20°), which is part of the blue/red spectrometer

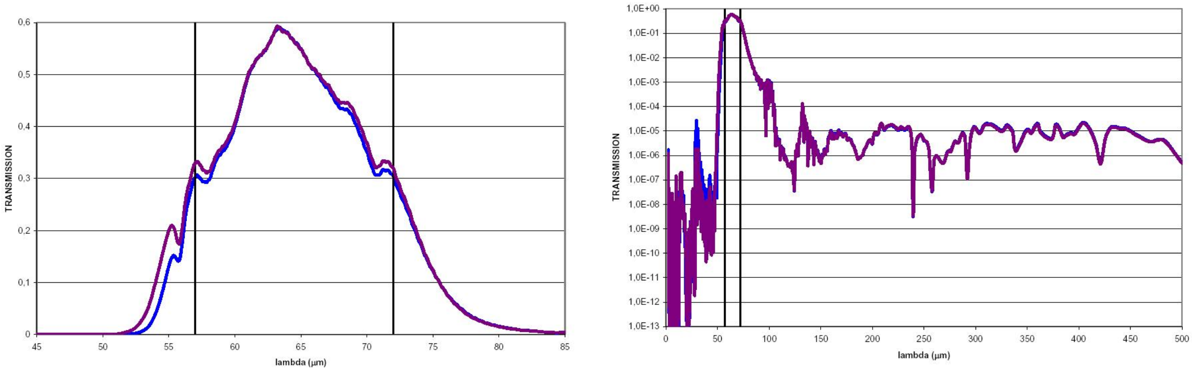

Figure 9: Blue spectrometer short wavelength band 57-72 μm. The blue line corresponds to the FLBS filter B662, the pink line to the FLRS1 filter B704.

optics, FLBS (part of the blue spectrometer) and FBBS2, located at the spectrometer filter wheel. The transmission values are 0.18% at 72 μm, $\sim$ 64% around 80-85/90-95/96-98 μm and 5% at 105 μm (see Fig. 10). The out-of-band suppression at short wavelengths is lower than 10^{-5} and at long wavelenghts lower than 10^{-4}. The in-band transmission efficiency is 48%.

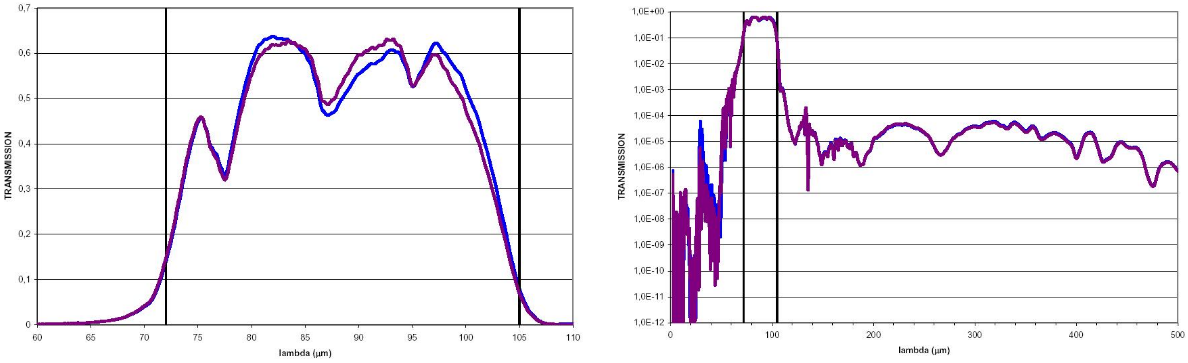

Figure 10: Blue spectrometer long wavelength band 72-105 μm. The blue line corresponds to the FLBS filter B662, the pink line to the FLRS1 filter B704.

5 Commanding, On-board Processing and Bandwidth Aspects

Tables 3 and 1 contain the commanding units for the PACS grating and the chopper respectively. These values can be used to command a default or a start position for the chopper and the grating.

From the commanding point of view there is no difference between a line and a range scan (OBCP 8 for 2 or 3 position chopping; OBCP 9 for 2 or 3 position chopping with dither).

5.1 OBCPs

Several on-board control procedures (OBCP) exist already for AOT design aspects. Modifications in the OBCP area are difficult, but still possible at this stage. These OBCPs are stored on-board and can be called by one single command. This will reduce the number of uplinked commands in order to stay within the uplink data rate limit. Switching on and off of filter wheel, grating, chopper and calibration source controllers is done by a very small number of individual commands and require therefore no specific OBCP. For spectroscopy, the following OBCPs exist (RD-08, RD-16):

	OBCP ID	NoP[1]	Seq.	NoP[2]
Switch photometry to spectroscopy	17	1	no	—
Ge:Ga Set-up (switch-on and configuration of CRE and Ge:Ga detector system)	23	12	no	—
Grating spectral line scan				
- chopped (2 or 3 positions)	8	22	yes	12
- chopped (2 or 3 positions) with dither	9	23	yes	12
- chopped_2 (fast 2 positions, ILT)	27	21	yes	11
- no chopping (absolute meas., ILT)	28	20	yes	11
Wavelength switch grating (frequency switching)	22	20	yes	11
Grating range scan	8	22	yes	12
Internal calibration spectroscopy	13	19	yes	9

[1]: The different OBCPs require a certain number of input parameters (NoP).
[2]: Some OBCPs call a DMC sequence which require again a number of parameters.

5.2 DMC sequences

Each OBCP with chopper and/or grating movements involves dedicated DMC sequences (only 1 DMC sequence per OBCP):

	DMC ID
Grating line scan with 2 or 3 position chopping (total of 12 input parameters)	8
Grating range scan with 2 or 3 position chopping (total of 12 input parameters)	8
Grating line scan with 2 or 3 position chopping with dither (total of 12 parameters)	9
Grating range scan with 2 or 3 position chopping with dither (total of 12 input parameters)	9
Line observation with wavelength switching (total of 11 parameters)	10
Chopped grating scans on internal calibration sources (total of 9 parameters)	11
Grating line scan with 2 position chopping (fast, for bright targets during ILT, 11 parameters)	12
Grating line scan without chopping (absolute measurements during ILT, 11 parameters)	13

These sequences ensure that the grating and chopper movements are synchronised with a destructive readout simultaneously in both channels. DMC sequences 8, 9, 10, 12 and 13 include already cycles on the internal calibration souces. It is of course possible to have also calibration measurements outside the sequences: before, after the observation or during slews (OBCP 13, DMC 11). The precise commanding within a DMC sequence can be found in RD-08. The duration of the sequences depend on certain input parameters, precise formulae can also be found in RD-08.

5.3 Cryogenic Readout Electronics (CRE)

The readout frequency of the Ge:Ga detectors is 256 Hz. Commandable aspects of the CREs are:

Parameter	Description	Value range	Default value	Comm. values
red_reset	red reset interval (# of samples)	16,32,64,128,256[1]	64	—
blue_reset	blue reset interval (# of samples)	16,32,64,128,256[1]	64	—
red_bias_d	detector bias red [V]	0...1 V	70 mV (287)	0...4095
red_bias_r	resistor bias red [V] (row #17)	0...1 V	0 mV (0)	0...4095
blue_bias_d	detector bias blue [V]	0...1 V	210 mV (860)	0...4095
blue_bias_r	resistor bias blue [V] (row #17)	0...1 V	0 mV (0)	0...4095
red_capacitor	Capacitor red	100fF, 300f, 1pf, 3pF	300fF (8^2)	0,4,8,12
blue_capacitor	Capacitor blue	100fF, 300f, 1pf, 3pF	300fF (8^2)	0,4,8,12
heater_blue_1c	blue HEATER_1C value	0...0.2mA	0.2 mA (4095)	0...4095
heater_blue_2c	blue HEATER_2C value	0...0.2mA	0 mA (0)	0...4095

Notes:

[1]: From the commanding point of view, it is possible to specify anything between 1 and 65535 readouts per ramp, i.e. reset intervals between 1/256 sec to 256 sec. In reality, the most probable values are something between 16 (ramp length 1/16th sec) and 256 (ramp length 1 sec). Shorter reset intervals are probably too much affected by CRE effects in the first few readouts per ramp, reset intervals longer than 1 sec are very likely influenced by strongly glitch effects.

[2]: The DMC UM specifications of the blue and red capacitors are wrong: The UM says that "8" corresponds to the capacitor 1 pF, but the 300 fF and the 1 pF capacitors are exchanged and a commanded "8" corresponded in reality to 300 fF.

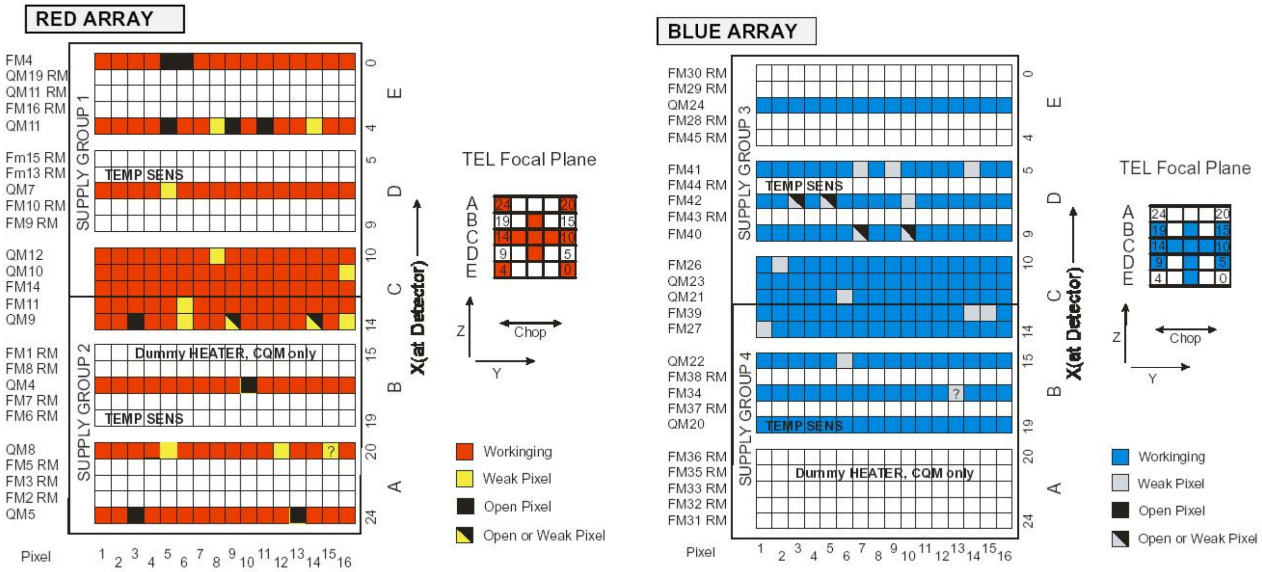

Figure 11: Current status, open and weak pixels in the CQM detector arrays. Pixel columns #0 (open channel) and #17 (resistor/dummy pixels) are not displayed. The bias_r values are applied to the resistor/dummy pixels [Rd-20].

An overview of the blue and red detector arrangements is shown in Fig. 11. An image slicer re-arranges the 2-dimensional 5×5 pixel field of view on the sky along the entrance slit of the grating spectrograph such that, for all spatial elements in the field, spectra of 16 pixels are observed simultaneously. Each detector module with 16 spectral pixels has in addition an open channel (#0) and a resistor/dummy pixel (#17), which are not shown in Fig. 11. The bias_d values are applied to the 16 detector pixels of all 25 modules, the bias_r values are applied to the resistor or dummy pixel #17 of all 25 modules. There are 2 temperature sensors in each of the two 16×25 arrays, the blue array has in addition a possiblity for heating (see command parameters heater_blue_1c and heater_blue_2c). Capacitor and reset interval can be selected, depending on the incoming flux, the glitch rate, S/N considerations, de-biasing effects, ...

5.4 On-board Data Reduction and Compression

The SPU has several means to manipulate the 256 Hz data coming from the spectrometer detectors via DMC:

1. It is possible to deselect individual pixels, detector moduls or channels via uploading specific detector selection tables, mainly to eliminate dead/weak pixels or to deselect one channal for a reduced data rate.

2. Ramps can be split into n sub-ramps of the same length (e.g. a 64 readout ramp can be split into 4 sub-ramps of 16 readouts each).

3. A on-board data reduction can be performed, allowing to do deglitching (glitch detection ON/OFF), ramp-fitting (either to sub-ramps or to full ramps) or calculation of mean values (useful for sub-ramps only)

4. It is possible to select a small number of pixels which will be transmitted raw, in addition to the reduced data. This will allow a direct comparison between the raw ramps and the results from the on-board data reduction by the SPU. Example with 3 raw pixels in blue and red: first compressed entity (2 sec) pixels #1,2,3, second compressed entity pixels #4,5,6, ... After 150 compressed entities (300 sec) the rotation is complete and all pixels have raw data for 2 sec each.

5. It is possible to command various reduction/compression modes (important ones are in bold-face):

Mode	Description	Explanation
0x10	**Default Mode**	Standard reduction (as specified in #3) & lossless compression
0x11	Double Compression Mode	mean of 2 consecutive ramps (only meaningful for slope fitting of ramps) & lossless compression
0x14	**Lossless Compression Mode**	no reduction, only compression (only possible for a max. of 1/4 of the pixels per channel → detsel-table)
0x17	Transparent Mode	no reduction, no compression (only possible for a max. of 14 pixel per channel in prime mode = 130 kbit/s)
0x18	4 sec Reset Interval Mode	nominal reduction & compression but with a different memory handling for 4 sec ramps
0x19	**Buffer Transmission Mode**	5 compressed entities of 2 sec each per channel for all pixels, $\sim$ 3 min trasmission time for the 10 sec data
0x20	Noise Resampling Reference	calculation of mean of a few raw ramps for SPU storage (currently not used)
0x21	Noise Resampling Mode	downlink of differetial measure between reference value and current value (currently not used)

For science observations there will be a standard SPU configuration, these various modes are only ment for specific test or certain calibration or engineering observations.

5.5 Bandwidth aspects

The relatively high telescope background and the readout noise spectrum require a rapid readout of 256 Hz of each pixel which leads to a very high raw data rate substantially above the maximum rate allowed by the Herschel on-board data handling system. The maximum raw data rate, produced by the spectrometer alone, is about 3600 kbit/s (2 arrays × 25 spatial pixels × 18 spectral pixels × 256 maximal readout rate × 16 bit) which needs to be reduced to the maximal downlink telemetry rate of 130 kbit/s. This rate includes the maximal allowed rates for PACS prime HK (up to 4 kbit/s), SPIRE non-prime HK (up to 2 kbit/s), HIFI non-prime HK (up to 2 kbit/s) and instrument events and TC verification (<1 kbit/s). The resulting nominal PACS science data rate is then 121 kbit/s, just below the maximum allowed downlink data rate of about 130 kbit/s. Out of that value about 2.4 kbit/s will be needed for PUS header/trailers and structure identifiers. In burst mode a rate of about 300 kbit/s might be possible (RD-13).

Therefore, the onboard data reduction and compression has to work very efficiently to reach the nominal transmission rate, especially since the transmission of several raw channels is necessary to obtain a solid data characterisation on ground. A combination of data reduction and lossless data compression is carried out by a dedicated Signal Processing Unit (SPU) within the PACS warm electronics. The data reduction part is implemented as either sub-ramp fitting or binning of n samples along the integration ramp. In either case, the lossless compression allows a data rate of 64 samples/s within the available telemetry bandwidth.

With respect to the AOT design one could think of deselection of data which are not requested by the observer, i.e. the parallel data in line and range spectroscopy mode. For line or range spectroscopy in first order for example, only the red detector array data would be taken, the parallel data in second (or third) order would be suppressed. But there are also good arguments to keep the parallel data:

- they might contain scientifically interesting data
- they might contain supplementary information, e.g. a continuum flux at 80 μm while observing a line at 160 μm
- they might be useful for specific calibration purposes, e.g. a nice line seen by chance in the parallel data might be useful for the wavelength calibration
- they might contain useful information for tracing the detector history (large glitches, dark current drifts, etc.)

In addition to the data rate aspect, one also should keep in mind that the parallel data are sometimes outside the nominal range and therefore suppressed by the order sorting filters. Examples: the 105 to 140 μm first order data have no useful parallel data in second or third order; the 140 to 160 μm data have only useful parallel data in second order; the longest wavelengths data in third order have no counterparts in first order (see Tbl. 3 or Fig. 21). In these cases parallel data can be completely ignored and a significant part of the bandwidth can be saved without loosing information.

The efficiency of on-board data reduction/compression will also influence the decision on parallel data transmission. High resolution line scans including the transmission of several raw channels could use up the full bandwidth. A transmission of parallel data would then only be possible by degrading the data quality of the primary line scan data (lower resolution or less raw channels).

6 Satellite and Telescope Issues

6.1 Pointing Modes

The general rules of pointing requests are:

- A single observation (defined as the smallest schedulable entity or CUS observation) cannot contain more than one spacecraft pointing command. The main advantage of this rule is the possibility to provide the necessary timings for the pointing mode and elements within it and the possibility to abstract the pattern on the sky in a suitable way for mission planning and pointing constraint checking.

- A spacecraft pointing command can be one of the basic pointing commands or a composite pointing command. The latter one contains several basic spacecraft pointing commands combined in such a way that in the CUS only one composite command is needed to achieve more complex pointings than would be possible with single basic pointing commands alone. This philosophy has to be respected when Instruments plans currently not available pointing modes. For instance, a forward - reverse pair of raster commands can be included in a loop when a raster repetition is requested. The two looped commands can form a composite request in a single command.

- Restrictions on combined usage of parameters relative to the spacecraft coordinate system and absolute with respect sky coordinates will apply. The reason of such a rule is that slewing times within a pointing mode can highly depend on the actual layout of the pointing pattern and the request has to deal with a worth case longest slewing time calculation. As an example, a raster with off position request has a fixed sky coordinate for the off position but the pattern can be freely rotated. The slewing time from raster positions to the off position therefore depends on the raster rotation, moreover, it will be different for each raster points. The slewing time therefore has to be the longest possible one. For elongated rasters and for certain raster position angles it may lead to significant overheads.

The currently available Herschel pointing modes are:

- **Fine pointing**:
  Single pointing position, staring mode.

- **Raster**:
  Raster pointing is a series of fine pointing observations of equal duration (t), separated by slews. M is the number of pointings per line (2-32) and N the number of lines (1-32), d_1 is the angular distance between successive steps (2 arcsec-8 arcmin; resolution 0.5 arcsec), d_2 between successive lines (2 arcsec-8 arcmin or 0; resolution 0.5 arcsec), ϕ is the rotation of the pattern axes with respect to local instrument axes (0-90°; resolution 0.1°; Q_{rast} are the quaternions of the first raster point (see Fig. 12). Note that d_2 being zero means that the M points of a single line are scanned N times. The duration of stable pointing at any position will be between 10 sec and 30 min.

- **Raster with an off position**:
  Raster pointing with OFF-position is a special form of raster pointing where, after a specified number of raster points (ON positions), the spacecraft slews to a predefined point (OFF position),

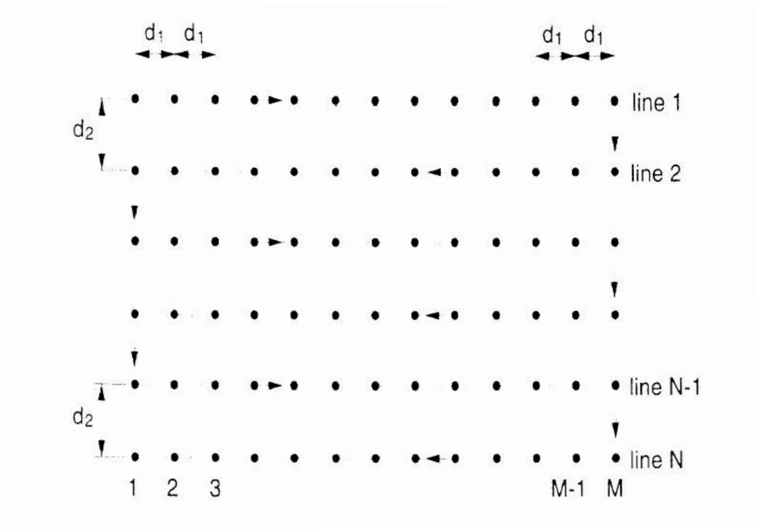

Figure 12: Raster pointing mode.

after which it resumes its raster pointing where it left the raster before going to the OFF position. The number of raster pointings (K) before going to the OFF position is determined by the time characteristics of the detectors. This form of raster pointing is shown in Fig. 13. The parameters ϕ, M, N, d_1, d_2 and Q_{rast} are the same as in nominal raster pointings, Q_{off} are the quaternions of the OFF position. K can take values between 2 and M×N, with the maximum value of K being equal to the total number of ON positions implies normal raster pointing with only a single OFF position pointing at completion of the raster.

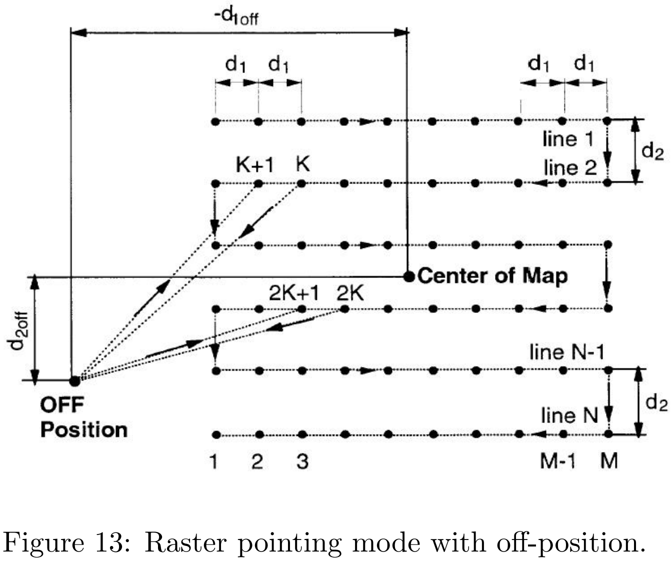

Figure 13: Raster pointing mode with off-position.

- **Line scanning**:
  This is a scanning mode along short parallel lines, such that the telescope axis moves as shown in Fig. 14, with the following parameters: N: number of lines (1-32), D_1 angular extent of the lines (1 arcmin - 20°, resolution 1 arcmin), d_2 the angular distance between successive lines (2 arcsec - 8 arcmin or 0, resolution 0.5 arcsec), ϕ defines the rotation of the scan lines with respect to the local instrument axes (0 - 90°, resolution 0.1 °), Q_{scan} are the quaternions of the beginning of the first scan line. Note that the minimum of d_2 being zero means that it is possible to scan N times the same line. The scan rate r is changeable by ground command between 0.1 arcsec/sec and 1 arcmin/sec with a resolution of 0.1 arcsec/sec.

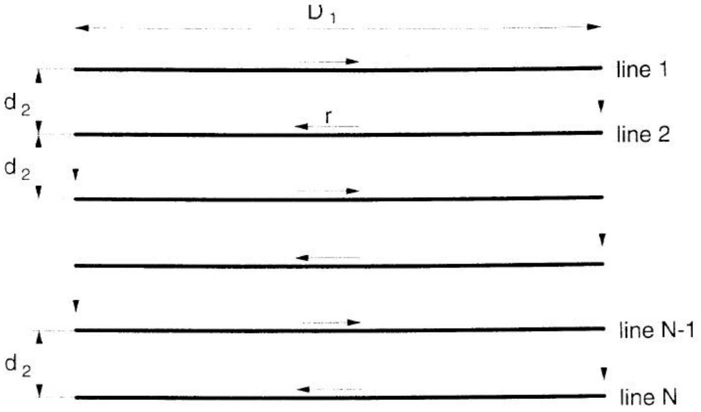

Figure 14: Line scanning mode.

- **Line scan with an off position**:
  Line scanning with OFF position is a special form of line scanning where, after a specified number of lines, the spacecraft slews to a predefined point (OFF position), after which it resumes its line scanning where it left the pattern before going to the OFF position (see Fig. 15). The number of lines (K) before going to the OFF position is determined by the characteristic stability time of the detectors. The line scan pattern is defined by the parameters Q_{scan}, ϕ, N, D_1, d_2 and r as given above, Q_{off} specifies the quaternions of the OFF position in the inertial coordinates. K can take values between 1 and N. The maximum value of K being equal to the total number of lines implies normal line scanning with only a single OFF position pointing at completion of the line pattern. The spherical coordinates d_1^{off} and d_2^{off} of the OFF position with respect to the centre of the map have to be within the range ±(0 arcmin - 2°).

- **Tracking**:
  The maximum allowed speed for solar system object tracking is 10 arcsec/min (10 arcmin/hour) relative to the tracking star. The trajectory of such objects will be described by Chebyshev polynomials or a parabolic fit approximation (see SER H-P-4-DS-SER-068, Issue 2.0, 21-02-2003 (Herschel/Planck ACMS).

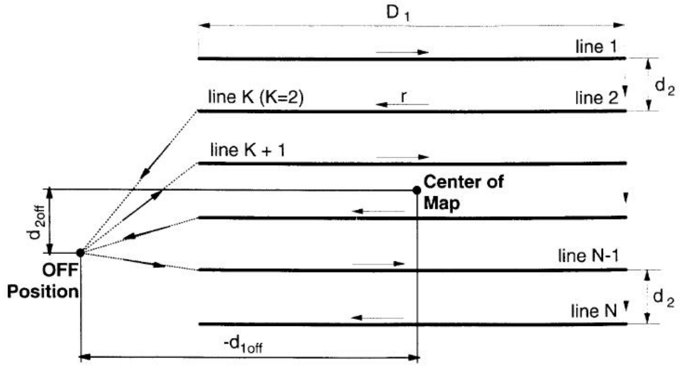

Figure 15: Line scanning mode with off-position.

- **Position Switching**:
  Position switching is an observing mode in which the instrument line of sight is periodically changed (via changing of telescope pointing direction) between a target source and a position off the source (n repetitions). This is a special case of normal raster pointing with the following raster parameters: ϕ (0 - 90°, resolution 0.1°), M = 2, N (1 - n), d_1 (2 arcsec - 2°, resolution 0.5 arcsec), d_2=0. The integration times in the "on" and "off" positions are equal and are within the range 10 sec to 20 min (depending on the throw).

- **Nodding**:
  Nodding is an observing mode in which the target source is moved from one instrument chop position to the other chop position (n repetitions). In this case the telescope pointing direction will change periodically in the direction of the instrument chopper throw. This is a special case of normal raster pointing with the following parameters: ϕ=0, M=2, N (1 - n), d_1 (2 arcsec - 16 arcmin, resolution 0.5 arcsec), d_2=0. The integration times in both positions are equal and are within the range 10 sec to 20 min (depending on the throw).

6.2 Satellite Slews

RD-025: The maximum slew rate will be 7 degrees/min (or larger) when the slew angle is large enough to permit full angular velocity. For slews smaller than 16 arcmin (ϕ in arcsec), the time to acquire the target will be:

$$\begin{array}{ll} \text{maximum:} & 10 + \sqrt{2\phi}\ \text{[sec]} \\ \text{goal:} & 5 + \sqrt{\phi}\ \text{[sec]} \end{array}$$

It will be possible to change via command the slew rate between 0.1 arcmin/s and 1 arcmin/s with a resolution of 0.1 arcmin/s. A slew of at least 90 degrees will be completed in 15 min, including settling time. It will be possible to execute each 22 hours, 2 of such slews without the necessity of wheel-momentum off-loading.

During satellite slews, the Herschel satellite shall provide all the resources necessary for operation of one science instrument in serendipity mode. Such science observations shall not put any demands on the spacecraft attitude profile. Mission planning shall allow instrument operations that are preparatory for the subsequent observations during slews. No PACS serendipity mode during slews is foreseen. The way the slew time is exploited scientifically is by using the slews for internal calibrations and configurations, effectively freeing on-target time. For the serendipity mode it is a requirement that SPIRE is put into Photometer Standby mode.

For PACS, the first part and last part of an AOT consists of internal calibrations and configurations that can be performed during the slew. An observation therefore has three durations associated with it: The total observation duration T_{tot}, the duration of the internal calibrations and configurations at the beginning of the observation T_{precal}, and the duration of the internal calibrations and configurations at the end of the observation $T_{postcal}$.

```
--slew----|-on-target1-|--slew--|--on-target-2----|--slew
|-precal1-|------obs1--|-postcal1-|-precal2|obs2--|post2
```

The mission planning system can calculate the effective on-target time for an observation as follows:

$$T_{off} = T_{tot} - min(T_{precal}, T_{free\_slew\_to\_n}) - min(T_{postcal}, T_{free\_slew\_to\_n+1})$$
$$T_{free\_slew\_to\_n+1} = T_{slew\_to\_n+1} - min(T_{postcal\_n}, T_{slew\_to\_n+1})$$

One possible calibration strategy is to identify profiles of operational days or parts of an observational day that only contain certain AOT types (e.g., PACS line scan spectroscopy, PACS range scan spectroscopy, PACS raster mapping photometry, ...). Per profile a specific strategy can be specified to schedule internal or external calibration observations. This can include the observations to carry out at the beginning and end of the OD, observations to schedule periodically troughout the OD, etc....

6.3 Telescope Mirror

TBD.

7 Spectrometer AOT Design

7.1 Goals of the Spectrometer AOT design

The most important goals of the spectrometer AOT design are the following:

- provide reliable and scientifically useful data
- provide flexibility for a wide variety of different observations and source constellations
- minimise the observing time for a given source in the sky
- establish a clear and easy to understand AOT concept for the observer
- optimise the calibration accuracy (e.g. by optimising the usage of the PACS internal calibration sources) under a given characterisation of the RSRF, flat fields, dark currents, straylight, ...
- find good strategies for the detector curing/flashing events, to minimize the time losses and to maximise the instrument performance
- take full advantage of the detector sensitivities
- enable a straightforward calibration and data reduction scheme
- provide a high enough data redundancy for removal of instrumental and space environment effects
- reduce energy dissipation of the instrumental parts to optimise the satellite lifetime
- avoid mechanical degradation of instrument parts, e.g. uneven mechanical wear of the grating which might then be problematic at later stages of the mission
- allow for an effective data reduction and compression to stay within the given data rate limits without loosing important information
- avoidance of critical events for PACS and for the whole satellite

All these goals shall be reached on basis of a simple user interface where observers only specify key astronomical information for a specific observation. The complex logic of instrument and satellite operations behind the AOT interface is currently under developement. It will be optimized during the upcoming IMT and ILTs.

7.2 Spectrometer setup

After the general switch-on of PACS (or after a safe or non-prime configuration), the instrument and the warm electronics have to be prepared for the PACS spectroscopy operational day. This is done in two steps.

The first step is called in CUS "SPEC_orbit_prologue". This script will switch on and set all required parameters for detectors, mechanisms and calibration sources for spectroscopy. In addition, the HK list, the temperature sensors, the FPGA timing and receiver options, the synchronisation source, the CREs and the SPU are configured. The SPU does not yet start the reduction/compression process. The execution of the "SPEC_orbit_prologue" takes 202 sec, but the calibration source will require another 40-50 min for stabilisation. Therefore, this procedure might actually be executed during the DTCP to avoid the loss of valuable observing time while the calibration sources are still stabilising.

The second step is the spectroscopy AOT prologue (CUS script: SPEC_aot_prologue) which is executed as a first step while the satellite is slewing to the target position. This procedure takes in total 34 sec and it contains the following key elements:

- Setting of the operational CRE bias voltages (see Sect. 5.3)
- setting of the default detector capacitors (currently the default capacitor is 1 pF)
- default setting of 64 readouts per ramp which corresponds to 1/4 sec ramps (256 Hz readout frequency)
- configuration of the default SPU reduction and compression mode. Currently the default settings are: 16 samples per subramp (which means a subdivision of each ramp into 4 subramps), 3 raw pixel per blue and red channel (the raw pixels are rotating, see Sect. 5.4), glitch detection off, mean value determination for each subramp, default compression mode (see Sect. 5.4)
- Move the filter to the default position "0" (specified in the "SPEC_MEC_Defaults" calibration file). This means that the short blue channel (55-72 μm) and the red channel (105-210 μm) can be seen in parallel. The filter movement takes about 15 sec.
- Movements of the chopper and the grating to central positions (specified in the "SPEC_MEC_Defaults" calibration file)

At this point, the spectrometer science data flow is enabled and running. Sky signals at approximately 175 μm (first order) and 58 μm (third order) are processed by the SPU and downlinked.

A summary of the CUS implementation is given in Tbl. 4.

Table 4: CUS scripts for the PACS spectrometer setup. Note: The Cal-U file "SPEC_MEC_Defaults" contains the default chopper, grating, filter wheel, calibration source 1 and 2 settings and positions.

CUS script	Calibration files	Duration	Remarks
SPEC_orbit_prologue	TBD.	202 sec	+ 40-50 min CSs stablisation time
SPEC_aot_prologue	SPEC_MEC_Defaults	34 sec	data flow starts

7.3 Spectrometer key wavelengths

The following key wavelength in the PACS regime have been defined (on basis of clean RSRF regions):

- blue spectrometer, in grating third order:

  - 58 μm, GPR 461 000 (prime key wavelength)
  - 62.7 μm, GPR 335 000
  - 69 μm, GPR 132 000
  - 55 μm, GPR 535 000

- blue spectrometer, in grating second order:
  - 82.5 μm, GPR 535 000 (prime key wavelength)
  - 74 μm, GPR 666 000
  - 87 μm, GPR 461 000
  - 94 μm, GPR 335 000
- red spectrometer, in grating first order:
  - 148 μm, GPR 666 000 (prime key wavelength)
  - 165 μm, GPR 535 000
  - 174 μm, GPR 461 000
  - 188 μm, GPR 335 000
  - 130 μm, GPR 794 000
  - 110 μm, GPR 927 000

The prime key wavelengths also yield useful data in the other band (as secondary key wavelength). They have been selected based on the CQM RSRF (see Figs. 16, 17).

The purpose of the key wavelengths is to perform quick well-defined calibration scans around these lines to determine the actual performace of the detectors and to connect the established RSRF to the scientific observation. During the scan the chopper will switch between the 2 PACS internal calibration sources. A typical example product of such a reference scan is given in Fig. 18.

In total, the 14 key wavelengths require only 7 different grating positions. Assuming ∼45 observations per operational day (RD-05) and at least one calibration scan per observation, this would give, on average, about 6-7 scans per keywavelength per operational day. In practice, only 3 grating positions (335 000, 461 000, 535 000) yield useful data in all 3 orders. The calibration data base will therefore be dominated by scans at these grating positions.

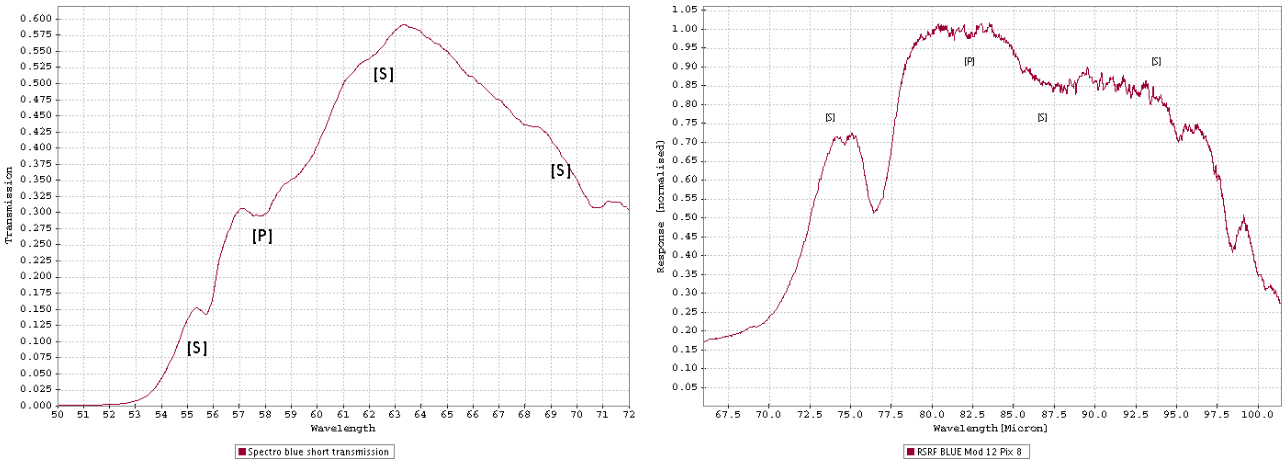

Figure 16: PACS blue spectrometer key wavelengths (3rd and 2nd order of the grating). [P]: prime key wavelength; [S]: secondary key wavelengths.

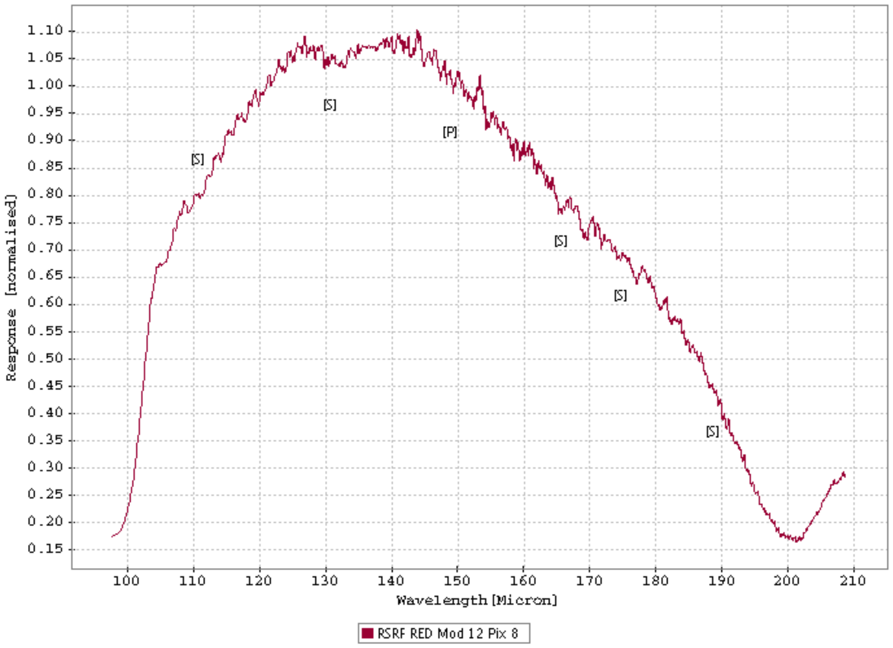

Figure 17: PACS red spectrometer key wavelengths (1st order of the grating. [P]: prime key wavelength; [S]: secondary key wavelengths.

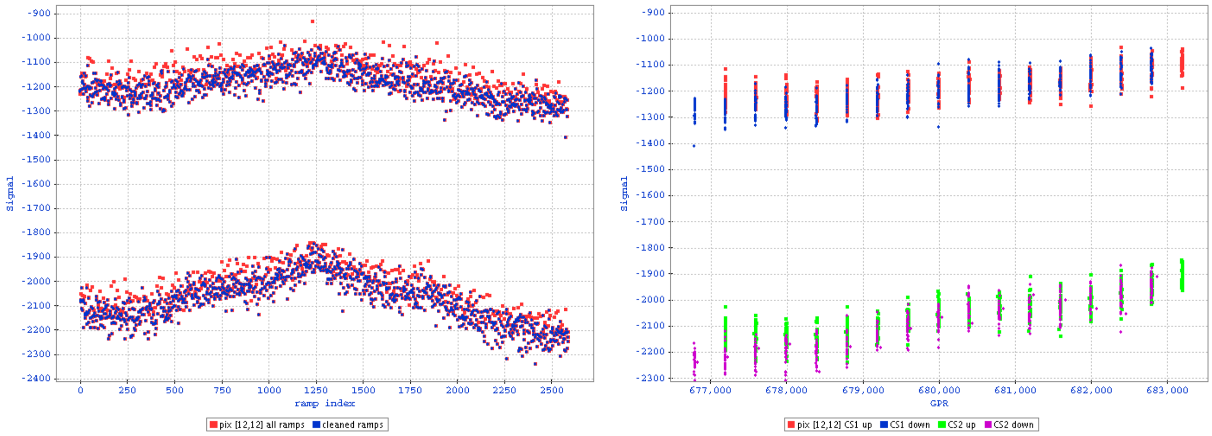

Figure 18: CQM measurement ”QILT_00095_SpecQuickCSScan_07.tm”, calibration scan at around grating position 676 800, chopping between the 2 calibration sources, OBCP 13. Left: signal against ramp index (time sequence). Right: signal against grating position (wavelength sequence).

8 Spectrometer Line Scan AOT

8.1 Introduction

An operational day with focus on PACS spectrometer line scan AOTs will start with the generic "SPEC_orbit_prologue" (duration 202 sec + 40-50 min CSs stablisation time). Now, the satellite stars slewing to the requested position for the first scientific observation. In parallel to the slewing, the "SPEC_aot_prologue" (duration 34 sec) is executed and the observational data flow starts and valid data are produced in both channels (by default in the short blue and in the red channel).

Directly after the "SPEC_aot_prologue a calibration sequence (see Sect. 8.2) is executed. After this sequence has finished and the satellite reached the target position, the first line scans will be executed. A limited number of relatively narrow emission/absorption lines can be observed for either a single spectroscopic FOV ($0.78' \times 0.78'$) or for a larger map. Background subtraction can be achieved either through standard chopping/nodding (for faint/compact sources) or through 'frequency-switching' techniques (for line measurements of bright extended sources) of the grating mechanism. After all lines have been completed, the satellite moves to a nod-position and the lines will be repeated in the same manner. If lines of second and third grating order are included, one or more filter switches are necessary.

8.2 General calibration block for line scan AOTs

8.2.1 General description

During operational days for PACS spectrometer observations, a calibration block will be performed during target acquisition before the actual science observation starts. This block contains chopped short scans on the two internal calibration sources at key wavelengths in either one, two or all three orders, depending on the consecutive science observations. Should the slew be faster than the duration of the set-up and calibration block, the S/C will wait for the end of these operations at the commanded [RA,DEC] before starting the science observation proper.

The calibration phase itself consists of up to three short up-down grating scans (one per each grating order present in the user given wavelengths). The scans are performed at one "key" wavelength per order, chosen to be the the wavelength closest to the mean value of the user given lines at that particular order. If the user specifies several different lines pertaining to the same grating order, the CUS logic will compute the mean wavelength of all those lines. The CAL observations themselves are performed starting with the shortest wavelength - highest order. The reason for this choice stems from the fact that the preceding set-up module will leave PACS order filter at the position of ORDER=3. For reasons that will be presented below, the calibration block finishes leaving the filter wheel at the position that the last observed science line would leave it. The total number of filter wheel movements within the calibration block depends on how many different orders have been given by the user. ORDER=1 has no effect as it does not require a filter wheel movement; ORDER=3 does not require a filter change since the filter was left there by the set-up procedure. In the general case of several ranges including ORDER=2, the number of filter movements during the CAL phase is more difficult to estimate (see below "PACS Line Spec Science Observation Phase"). The worse case is two filter movements: from ORDER=3 to ORDER=2 and then back to ORDER=3 before finishing the CAL cycle.

8.2.2 CUS implementation and time calculation

The calibration scan itself is performed by the OBCP 13 ”internal calibration spectroscopy” via the CUS script ”PacsLineSpecSlewCal” which requires the Cal-U file ”OBCP13params”. Currently, it comprises of one (p_1) grating up-/down scan sequence of 16 steps (p_3), a step size of one pixel, with the chopper doing 1 cycle (p_5) between the two internal calibration sources for each grating position. On each chopper plateau, 4 clean reset intervals (p_7) are taken, the fifth is always affected by the chopper transition. The grating scan start position is at the moment identical to the key wavelength position, but will be calculated later on in such a way so that the key wavelength will be in the center of a detector module in the middle of the up- and down-scan.

In total, this leads to $2+p_1\cdot(1+2\cdot p_3\cdot(1+2\cdot p_5\cdot(1+p_7)))ramps = 355\,ramps$, corresponding to 88.75 sec DMC sequence time for 1/4 sec ramps (or 44.375 sec for 1/8 sec ramps) plus about 25-30 sec for the grating movements from and to default position. For 2 orders, the total calibration time is approximately 230 sec, plus 15 sec in case of a filter change. For 3 orders, the total time is $\sim 3\cdot 115\,sec + 2\cdot 15\,sec = 375\,sec$. For 1/8 sec ramps the times are 70 sec for 1 key wavelength, 140 sec for 2 (+15 in case of a filter change) and $\sim 3\cdot 70\,sec + 2\cdot 15\,sec = 240\,sec$. All calculations take an operational grating speed of 4°/sec into account (during CQM the speed was only 1°/sec).

8.2.3 Open points

- In order to make use of the full 16-step scan, it will be necessary to let the detectors stabilise before starting the scan. Or, alternatively, start the scan further away from the key wavelength (e.g., $\geq$ 20 steps per scan direction)
- Is one chopper cycle per grating position enough? But 2 cycles would almost double the total time per line scan.
- Could the 4 ramps per chopper plateau shortened to 2 or 3 clean ramps? This question will be addressed during the EQM-IMT.
- In case of 2 (or 3) key wavelengths in the calibration block which require the same grating position: Should one (or two) identical scan(s) be skipped?
- What is the exact step size to move the grating by 1 pixel, currently we use 400 units step sizes
- Is it enough to execute this calibration block only once? Is a repetition necessary after the science line scan observations are completed? If the science scan observations are very long, is it necessary to interrupt and execute the calibration block again?
- Is it sufficient to have only calibration scans on one key wavelength per order?
- Other points?

8.2.4 Planned EQM-IMT procedures with respect to OBCP13

- ”Tuttifrutti-sequence”: OBCP13 sequence with 2 chopper cycles with 3 clean ramps per chopper position for each grating position, 16 steps up-/down, stepsize 1/3 of a pixel.
- Test of internal calibration blocks: OBCP13 sequence with 1 chopper cycles with 1 (3, 5, 7, 15) clean ramps per chopper position for each grating position, 16 steps up-/down, stepsize 1/3 of a pixel. Repetition for 3 different grating positions.
- Modifications necessary? 2 clean ramps per chopper plateau? 1 clean ramp per chopper plateau, but 2 chopper cycles per grating positions?

8.3 PACS Line Scan AOT with chopping-nodding

8.3.1 General description

This AOT is meant to perform an observation of one or several spectral line features (up to ten lines can be studied within an observation). The S/C may be used in the staring or in the raster modes. Nodding is permitted in either pointing mode. In all four cases, the use of the internal chopper is imposed by the design of the AOT

8.3.2 User input to PacsLineSpec

For each target, the observer specifies, in addition to the target position, one or more lines either manually or from a database, together with the redshift, the optical or radio radial velocity. The on-source integration time has to be specified for each pointing.

The setting of the observing mode has the following options:

- Map choice: pointed, small map or large map
- Nodding: on or off
- Background subtraction: Chopping or frequency switching; in case of chopping:
    - selection of the chopper avoidance angle (this would affect scheduling of the observation)
    - selection of the chopper throw: small, medium or large;

  no further options in case of frequency switching
- Reference off-position: yes or no; in case of yes: specifications of the off-position
- in case a solar system target was selected: tracking on or off

For each user defined wavelength, PACS will perform an up/down grating scan, of such an amplitude that the given wavelength will be successively seen by all 16 ”spectral” pixels. In fact, the grating excursion is slightly larger so that some baseline will be explored beyond pixels 1 and 16. The user has no control on the grating excursion nor on the sampling interval. These parameters are defined, per wavelength range, in the U-CAL file GRAT_wave_pos, see Appendix D. The sequence of internal PACS operations necessary to observe one line is governed by OBCP 8 (or alternatively, by OBCP 27) and its associated DEC/MEC sequence (Section 5).

The astronomer can enter into HSPOT how many seconds he/she would like to spend to study one line, each line accepts its own observing time. The CUS logic will select the OBCP 8 (OBCP 27) parameters that will result in a time close to the given time. The actual observation time will not be exactly the same for two reasons: (1) the duration of the line scan is determined by a number of parameters that do not change continously (number of readouts per chopper position, number of chopper cycles at each grating position, etc.) and (2) CUS will estimate the various overheads incurred (moving wheels, advancing the grating to its start position, telescope slew times, etc.) and add this time to the OBCP 8 (OBCP 27) proper execution time. CUS will report the computed total observing time as well as the expected RMS fluctuations, see Section 8.3.3. CUS will also report the breakdown of the total time as ON-source time, CAL time and overhead time. In general, longer observations give a better overall efficiency as some overheads tend to be independent of the total observing time or scale differently with the parameters of OBCP 8 (OBCP 27). Note that HSPOT expects a time per pointing and per line, including nodding. If the demanded observation is of the raster type, the total reported time will add up the times at each raster position, including slew times.

The OBCP 8 (OBCP 27) parameters selected by CUS based on the time given by the user are tabulated in the U-CAL file OBCP8params, see Appendix D.

8.3.3 CUS implementation details

We saw in Section 8.2 that the calibration phase is performed starting with the shortest key wavelength. For the science observation, the current strategy is different. The lines given by the HSPOT user are sorted by increasing grating start position. This is generally equivalent to sorting by wavelength, but it may mix orders, upsetting the wavelength ordering. As an example, assume that five wavelengths have been entered in HSPOT. Arranged by increasing wavelength, CUS will construct the following internal table:

Wavelength	Start grating position	Grating order
88.0	440657	2
57.0	482995	3
122.0	844549	1
145.0	684875	1
205.0	153572	1

Since the science observation is performed using up/down scans, the ending grating position will be the same as the starting grating position. From the table above, we see that going from 57 μm to 122 μm entails a rather large grating movement; same when going from 145 to 205 μm. Currently, we believe that large grating excursions may be more perturbing to the detectors that moving the filter wheel. For this reason, CUS sorts the observations by grating position; the current implementation will observe the sequence 205.0, 88.0, 57.0, 145.0, and 122.0 μm. Each line is then scanned up and down, with the chopper switching between on- and off-position for each grating step. After all lines in that order have been scanned, the telescope nods to the off-position and all lines are repeated in exactly the same manner, starting again with the lines corresponding to the smallest grating position.

The fact that nodding and raster are allowed for this AOT introduces some AOT design constraints: all nod cycles have to have the same duration. There are no provisons for the S/C to perform "duration asymmetrical" nods. Likewise, raster dwell times must be the same for all raster positions. The immediate consequence is that a nod cycle or a raster point must contain the ensemble of lines given by the user since there is no fail-proof way to split the given lines into smaller groups of equal duration. Even if raster scans could be repeated (one repetion per group of lines), the dwell time are not be allowed to change in the repetition pattern.

The duration of observing the ensemble of lines (curently up to ten) may result in too long an observing sequence, with the risk of response or gain drifts before a nod can be performed. It cannot be ruled out that CUS would issue a warning message if tests confirm this to be a problem.

There is a second AOT design constraint. When a science observation starts, after the calibration cycle has completed, PACS will be in a state that may not be the same as that after having completed the first leg of the science observation (leg here is either a nod position or a raster point). This means that the time needed for PACS to reconfigure and ready itself to perform the second leg will be different from the time used following the calibration observation; the second leg may then take less or more time than the first leg, violating the equal duration constraint. This is the reason why, as mentioned in Section 8.2, the calibration block leaves PACS in the same configuration as the one that will prevail at the end of the first observing leg.

For flat-fielding the calibration sources might be used, depending on their isotropy and homogeneity performance. If the detector response is changing on very short timescales (due to high energy particle impacts), it would also be possible to chop to both PACS internal calibration sources for each grating position.

The pixel size in spectroscopy mode undersamples the PSF especially at short wavelengths. In some cases it will be necessary to retrieve some more spatial detail by rastering in sub-pixel steps.

8.3.4 Time and resolution calculations

Table 5: PACS grating/pixel spectral characterisation. Note: the (+6) and (+9) correspond to a scan extension of 1.5 FWHM to both sides.

n	λ [μm]	FWHM [km/s]	total coverage 16 pix [km/s]	total coverage 2×1.5 FWHM extension	pixel per FWHM	number of steps (1/2 FWHM sampling)	number of steps (1/3 FWHM sampling)
1	105	318	2856	3810	1.78	18(+6)	27(+9)
1	158	239	1572	2289	2.43	13(+6)	20(+9)
1	175	212	1280	1916	2.65	12(+6)	18(+9)
1	210	140	720	1140	3.11	10(+6)	15(+9)
2	72	164	1840	2332	1.42	22(+6)	34(+9)
2	105	80	720	960	1.78	18(+6)	27(+9)
3	55	114	1448	1790	1.26	25(+6)	38(+9)
3	72	55	615	780	1.42	22(+6)	34(+9)

The grating will be scanned by a number of discrete steps around a specified centre position such that all detectors are carried through the line (each pixel sees the line). At the highest resolution the total coverage will be between 615 km/sec (at 72 μm in 3^{rd} order) and 2856 km/sec (at 105 μm in 1^{st} order), including an 1.5×FWHM extension to both sides of the scan leads to a coverage between 780 km/s and 3810 km/s (see Tbl. 5). Without specifying a range it will therefore be difficult in this mode to observe some extragalactic lines which are “wide” with respect to the 600-700 km/s minimum instantaneous spectral coverage at certain wavelengths (see Tbl. 2, 5). It has to be seen if the range spectroscopy would be an option for such wider lines or if one should keep the wavelength range option also for the line spectroscopy (and ask explicitly for the expected line width).

The shortest possible duration of an individual line scan can now be extimated from the number of grating steps × 2 (up-/down-scan) × 2 (repetition for the other nod position) × the number of chopper plateaus per grating position × the integration time per chopper position.

The current implementation uses OBCP 8 for the line scans. This means that for each grating position there are 4 chopper plateaus (On-OFF1-ON-Off2). Assuming only one 1/4 sec ramp per chopper plateau (plus additionally 1 ramps for the mechanism movement) would result in a total time of 2 sec per grating position. A grating scan with 35 steps up and down results then in approximately $2(up/down) \times 35(steps) \times 2\,sec \times 2(nod) + grating/slewingoverheads = 280\,sec + 100\,sec + 8\,sec = 388\,sec$ (this would apply to a line scan of a bright line at 65 μm). The same observation but now with OBCP 27, which performs only one ”On-Off” chopper cycle per grating position, would lead to a total time of 248 sec, but the on-source time is only half as compared to the OBCP 8 scan.

8.3.5 Open points

- how long do the signal drift in the blue channel after filter changes for typical grating positions?
- how are the signal drifts in the blue and red channel after fast grating movements from a low to a high flux regime? Answer: see report on ”Detector Memory/Transient Tests During CQM ILT”. Going from low to high fluxes causes signal drifts for up to 30 sec. From high to low the effects are not that severe.
- Depending on the stability of the detectors, it might be necessary to perform the telescope nodding after each line (instead of after all lines within one order). But this will cause overheads due to the increased number of telescope nods.
- If somebody specifies 10 lines which are all within the same order: Are the detectors stable enough to perform all lines in each nod position without looking at the internal calibration sources? Can the responsivity drifts be eliminated from the measurement sequence without information from the calibration sources?
- what would be the best sampling density for a line scan? a) Nyquist sampling (grating step size 1/2 FWHM) at each wavelength → number of grating steps will depend on the wavelength (about 10 steps at 210 micron and about 25 steps at 55 micron); advantage: all products have the same sampling and the observation time can be kept as short as possible, but depends on the wavelength; b) always use the same number of steps to have at least Nyquist sampling at the shortest wavelength and much better sampling at long wavelength → approximately 25 steps (this gives a sampling of

about 1/2 FWHM at 55 micron and 1/5 FWHM at 210 micron) advantage: always the same product with the same duration

- How far out (beyond the 16 pixels) should the scans go? 1, 2 or 3 FWHM?
- do we really need an off-position for large maps? sky off-positions are very likely included in the large maps and for a quick reference scan on the internal CSs it would be enough to stop the raster for a short period and then continue in the same position. This would avoid two telescope repointing overheads.
- The priorities in the Cal-U table "OBCP8params" have to be set with respect to the performance of the detectors under space environment conditions: increasing the number of ramps per chopper plateaus vs. more on-off chopper cycles vs. more up-/down-scans vs. more nod-cycles.

8.3.6 Planned EQM-IMT procedures with respect to line scan evaluation test

- "Tuttifrutti-sequence": OBCP 8 "chopped 3 positions scan" with 16 steps up and down, stepsize 1/3 pixel, 2 chopper cycles On-Off1-On-Off2, 1 chopper cycle on the CSs for each grating position, 3 clean ramps per chopper position.
- "Tuttifrutti-sequence": OBCP 9 "chopped 3 positions scan with dither" with 16 steps up and down, stepsize 1/3 pixel, 2 chopper cycles On-Off1-On-Off2, 1 chopper cycle on the CSs for each grating position, 3 clean ramps per chopper position, dithering on the off-positions.
- "Tuttifrutti-sequence": OBCP 27, "fast chopped 2-position scan" with 20 steps up and down, stepsize 4 pixels, 2 chopper cycles On-Off, 1 chopper cycle on the CSs for each grating position, 3 clean ramps per chopper position.
- "Tuttifrutti-sequence": OBCP 28, "fast 1-position scan with CSs", 20 steps up and down, stepsize 4 pixels, 1 chopper cycle On-CS1-CS2 for each grating position,3 clean ramps per chopper position.
- Line scan AOT (OBCP 8) in first order, grating position 535000, PACS FWHM 2.5 pixels with variation of the calibration concept: 32 grating steps up- and down-scan, with 2 chopper cycles On-Off1-On-Off2, 1 chopper cycle on the CSs for each grating position, 3 clean ramps per chopper position, stepsizes 1/2 pixel (1/5 FWHM), 0.83 pixel (1/3 FWHM), 1.25 pixel (1/2 FWHM)
- Line scan AOT (OBCP 8) in first order, grating position 535000, PACS FWHM 2.5 pixels with variation of the calibration concept: 32 grating steps up- and down-scan, with 2 chopper cycles On-Off1-On-Off2 for each grating position, no chopper calibration cycle, 3 clean ramps per chopper position, stepsizes 0.83 pixel (1/3 FWHM)

8.4 PACS Line Scan AOT with frequency switching

8.4.1 General description

For the frequency switching mode, a tradeoff between a simple switch and a repetitive fast scan has to be made. The frequency switching option is very efficient, because 100 % of the integration time is spent on target and it can be used for large extended sources since no clean reference field is needed. But this technique eliminates the continuum information. In the following cases the required baseline estimate will lead to unrealistic results: 1.) a noticable gradient is present in the continuum flux over the performed frequency throw; 2.) blends or line forests disturb the frequency switch interval. The continuum gradient influence can be minimized by using only small frequency throws (very close to the selected line). Larger frequency switches should be accompanied by additional low resolution range scans for better continuum estimates.

For frequency switching, the observer should be warned to check the available spectral information of galactic extended sources (e.g. diffuse molecular clouds, bright cirrus fields, star forming regions, photo-dissociation regions, photo-ionized regions, ...) in the vicinity of the selected line.

Frequency switching close to grating order cut-offs or into a neighbouring order might be difficult to calibrate. Here, the changing spectral resolutions and possible band edge effects might degrate the outcome of this technique.

For flat-fielding the calibration sources might be used, depending on their isotropy and homogeneity performance.

8.4.2 CUS implementation and time calculation

TBD.

8.4.3 Open points

TBD.

8.4.4 Planned EQM-IMT procedures with respect to frequency switching

- "Tuttifrutti-sequence": OBCP 22, "Wavelength/frequency switch grating": 2 complete cycles of 10 grating cycles grat_On-grat_Off1-grat_On-grat_Off2, followed by 1 grating cycle grat_On-grat_Off1-grat_On-grat_Off2 on CS1, followed by 1 grating cycle grat_On-grat_Off1-grat_On-grat_Off2 on CS2 with 3 clean ramps per grating position.
- two different lengths of grating plateau: 4 ramps and 16 ramps
- different size grating off-position movements: 8 pixel, 10 pixel, 12 pixel, 14 pixel
- full frequency switch concept (grating off position 12 pix; repetition with line position shifted by 1/3 PACS FWHM = approx. 3/4 of a pixel at 150 micron): grating off positions +/- 12 pixel; line on pixel position 8.50, 9.25,7.75

9 Spectrometer Range Scan AOT

9.1 Introduction

Like the previous AOT, this one also performs an observation of one or several spectral line features (up to ten lines can be studied within an observation). The S/C may be used in the staring or in the raster modes. Nodding is permitted in either pointing mode but the raster mode will be excluded under certain user input cases. In all cases, the use of the internal chopper is imposed by the design of the AOT. Unlike the PacsLineSpec, the user can freely specify the explored wavelength range or choose a predefined range that will cover the entire bandwidth of PACS.

9.2 User input to PacsRangeSpec

For AOT PacsLineSpec the user entered a number of wavelengths; here the user enters a number of wavelength ranges, viz. low and high wavelength pairs; the option ”RANGE” in HSPOT. Alternatively, the user may choose the mode ”SED”; here the CUS logic will use an internally defined range such that the entire bandwidth of PACS will be covered in two distinct grating scans. For most of the coming descriptions, no distinction is made between RANGE and SED modes since the SED mode can be considered as an observation with a predefined range.

For each user defined wavelength range, PACS will perform an up/down grating scan, of such an amplitude that the given bracketing wavelengths will be successively seen by all 16 ”spectral” pixels. In fact the grating excursion is slightly larger so that some baseline will be explored beyond pixels 1 and 16.

The astronomer has also control on the sampling interval, given by the HSPOT options ”high”, ”medium”, or ”low” for RANGE and the options ”fast”, ”slow”, or ”normal” for the SED mode[1]. Table 6 lists the particulars of each option.

Table 6: Range and SED mode options.

Mode	Option	Description
RANGE	high	oversample at 3x Nyquist
	medium	oversample at 2x Nyquist
	low	sample at 1x Nyquist
SED	fast	HF to explain how he chose sample rates
	normal	
	slow	

The allowed range intervals are defined in U-CAL file SPEC_BAND_params. Note that for the sole purpose of defining the ranges equivalent to the SED mode, its bracketing wavelengths are identified in the file as the non existing orders 4 and 5. The sampling intervals corresponding to Table 6 options are also defined in SPEC_BAND_params for the RANGE mode and in file SPEC_SED_parameters for the SED mode (App. D).

---

[1] HSPOT uses fast, medium, and low for SED; have renamed to fast, normal, and slow to better convey the notion of time needed to complete SED scan.

Spacecraft raster mode is not allowed for all combinations of input parameters to avoid potentially extremely long observation sequences. We think that observations of an exploratory nature fall in one of two categories: (1) exploring a large sky region for the existence of one or two spectral lines, or (2) exploring one sky region for the presence of line features within PACS spectral range. Rastering is allowed for type (1) observations and generally excluded for type (2). We also have considered that some astronomers may want to perform exploratory observations for which nodding is not wished since it will double the exploration time. Hence some HSPOT parameter combinations allow the astronomer to not select the "nodding" mode. The following Table shows the matrix of possible S/C pointing modes:

INTERNAL NOTE: Table to be reviewed....Might be easier to authorize NoNODDING everywhere and write a strong warning in the User's Manual. Current CUS will authorize any combination (constraints shall be handled by HSPOT to allow complete CUSGUI latitud for calibration scientists)

```
  |Range Mode \ Spacecraft  pointing modes
+------------+------------+-----------+
|       | Staring    |   Raster  |
|       +------------+-----------+
| SED        |     |        |
| options    | NoNODDING  | NoNODDING |
+------------+------------+-----------+
| slow       |      X     | no raster |
+------------+------------+-----------+
| normal     |      X     |  X     |
+------------+------------+-----------+
| fast       |      X     |  X     |
+------------+------------+-----------+
| RANGE      |     |        |
| options    |     |        |
+------------+------------+-----------+
| low        |     |        |
+------------+------------+-----------+
| medium     |     |  X     |
|------------+------------+-----------+
| high       |     |  X     |
+------------+------------+-----------+
```

```
NOTES: - NoNODDING checked ("X") means that the astronomer may chose not to nod,
         otherwise NODDING is invoked by CUS (number of cycles given by total
         time spent per range)
```

Notes:

1) Dithered scans will be very time consuming. Currently, in dithering mode the chopper performs a random pattern, but not every grating position will see the full dither pattern. This will be difficult to analyse due to inhomogeneities.

2) Undersampling/Optimal sampling/Nyquist sampling: The current calculations show that 3rd order observations

with fixed grating position are undersampled → grating scans with well-selected step sizes are required to obtain optimal sampling; between 140 and 210 μm the grating provides Nyquist sampled data without moving the grating (oversampling factor ≥ 2).

9.3 CUS logic and feedback to the user

In line spectroscopy mode the range (even if not specified) should be given back to the user as an information via the AOT user interface (calculated through the AOT logic), similar for the integration time and S/N. The pixel size in spectroscopy mode undersamples the PSF especially at short wavelengths. In some cases it will be necessary to retrieve some more spatial detail by rastering in sub-pixel steps.

9.4 Example: Fast full spectral scan

9.4.1 Description

Here we describe in detail how a fast full spectral scan looks like (more details are given in the document PICC-ME-TN-016). The requirements for such a scan were: shortest possible execution time, sufficient dwell time for each grating step to allow for at least one on-off chopper cycle and to obtain Nyquist spectral sampling for the entire wavelength range.

Spectral scans have been executed during the CQM ILT at various grating step sizes, ranging from about 100 to 1600. Based on the theoretical spectral resolution given in PICC-ME-SD-004 a grating stepsize corresponding to a HWHM of a spectral resolution element can be derived (Fig. 19). This stepsize would allow to just fully sample the spectra on each single pixel. In a fast scan this obviously causes an unacceptable large number of grating steps ($\sim$5000 = 2000, 2000 and 1000 steps in 3rd, 2nd and 1st grating order respectively), which lead even at short reset intervals to typical execution times significantly larger then 1 hour.

Making use of the simultaneous spectral sampling of the 16 pixels available for one spatial pixel, larger stepsizes are possible, while still providing the full spectral sampling. In order to arrive at the maximum stepsize possible which still covers the whole PACS spectrometer wavelength range with Nyquist sampling, the CQM ILT wavelength calibration has been taken and the spectral samples for a number of different stepsizes have been calculated. The results for the three different grating orders are shown in (Fig. 20). The required stepsizes are 2500, 2500 and 2400 for grating orders 1, 2 and 3 respectively. Within the first grating order, the position range between 95000 and 535000 is sampled both by the scan covering the second order and in the third order. Therefore the wavelength range 165-210μm will be sampled much better than all the other ranges. The whole spectral coverage is obtained with two grating up-down scans. Within the first scan, 1st and 2nd order are scanned simultaneously and within the second scan 1st and 3rd order. A further increase in the stepsizes would lead to spectral regions which undersample the PACS spectral instrumental profile. The presently derived stepsizes are certainly only estimates based on the CQM ILT wavelength calibration.

Although the grating drive has shown to be within specifications during the CQM ILT, it should be noted that grating moves for larger steps require considerable time to stabilize. Stabilization within ±8" is reached only after about 0.3 sec. Any larger steps as proposed above will even increase this stabilization time to typically close to half a second. Therefore such a quick scan requires, that at least one full on-off chop cycle is being done starting 0.5 seconds after each step. Since the chopper movement is carried

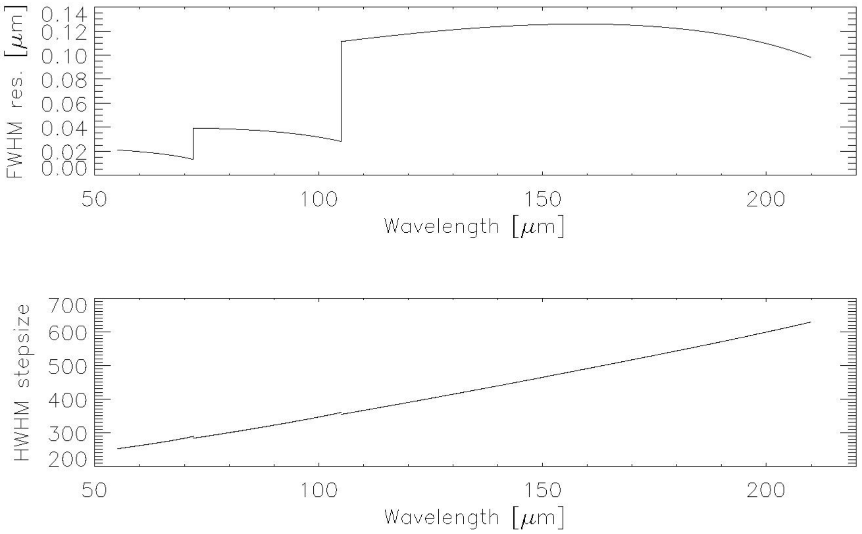

Figure 19: Upper plot: PACS spectroscopy FWHM resolution (PICC-ME-SD-004) in micron; Lower plot: related HWHM grating stepsize in grating units for Nyquist sampling per pixel.

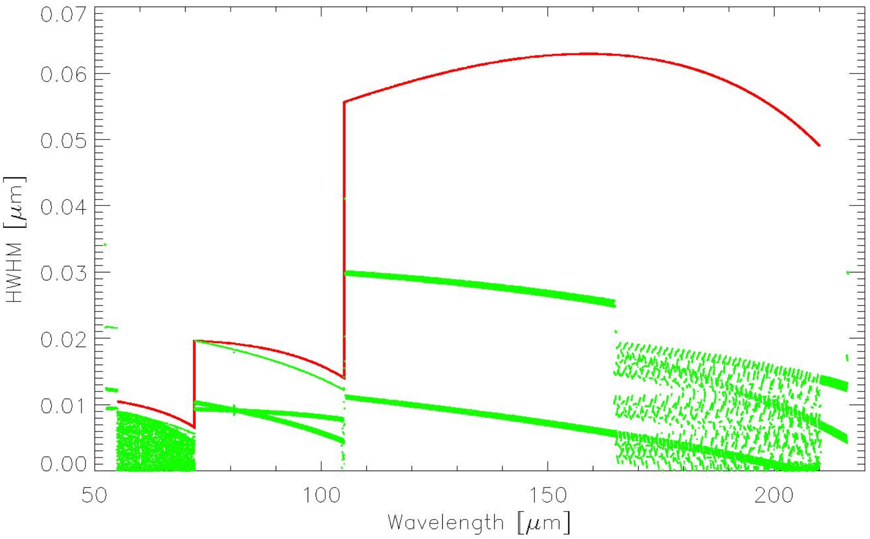

Figure 20: Red: Minimum required spectral separation in micron between samples for Nyquist sampling. Green: Actually obtained sampling for grating scan stepsizes of 2500, 2500 and 2400 in 1st, 2nd and 3rd orders.

out also only at a finite speed, at least 2 detector integration ramps are required per chopper plateau.

SPU CPU workload and compression ratio limitations are a further consideration requiring at least 32 readouts per ramp. In other words this means an integration ramp length of 1/8 sec, and a rectangular chopping frequency of 2 Hz, which gives 2 full chop cycles per commanded grating position.

Potential data losses by upsetting the detectors through cosmic ray hits suggest that additional data redundancy is required by executing the grating scan in both directions, i.e. up and down. It may appear attractive to double the proposed stepsizes and in turn shift the down scan by half a stepsize to obtain the same sampling within half of the time. However, as explained above, within such a scan the grating position would hardly stabilize before the next move and therefore it is not considered here. Only dedicated tests within the FM ILT could show whether grating scans with large non-stabilized steps can still produce acceptable spectra.

9.4.2 Nodding and Internal Calibration Strategies

The need for spacecraft nodding for signal reconstruction and internal calibrations within still TBD time intervals requires to break the sequence of grating up-down scans. Suitable entry points for internal calibrations would be at present at the begin, at the end and inbetween the two required grating scans. This is considered sufficient for internal calibrations, since the duration of individual up-down scans is typically of the order of $\leq$12 minutes. Similarly, the spacecraft nodding could be carried out after each up-down scan, i.e. having one up-down sequence at nod position A and then on position B right after. Since each up-down grating sequence in this AOT has a different length, it is important to note that at least two pointing requests for nodding would be required to execute the total full scan, when switching after each up-down sequence. As an option, one could even break the up-down sequences into smaller pieces in order to nod more frequently. It is not considered to interrupt for nodding or internal calibrations between the end of the up- and before the beginning of the down-scan. The present DMC sequences would not allow for such a scheme and in order to repeat an up-scan at the other nod position would require the grating to execute a rather large move back to the original start position.

An optimistic estimate for the times needed for internal calibrations, spacecraft movements and other overheads may be around 10% of the total time, i.e. $\sim$4 minutes.

9.4.3 Conclusions

- Proposed grating stepsizes are 2500, 2500, 2400 for 1st, 2nd and 3rd order respectively.
- The total number of required grating steps is 567.
- Assuming 32 readouts per ramp, 2 ramps per chopper plateau, 2 chopper cycles per grating position and 10% overheads a total execution time of 21 minutes can be derived for a single up-down sequence.
- A chopped and nodded, fully sampled full spectral range grating scan would therefore last of the order 42 minutes.

9.5 Planned EQM-IMT procedures with respect to range scan evaluation tests

- Medium sampling grating scan (OBCP 27), chopping between center field of view and one CS, then repeat for the other CS, 400 steps up and down, stepsize 6 pixels, 3 clean ramps per chopper position.

- Sparsely sampled scan on CS1 (OBCP 27), 100 grating steps with stepsize 20 pixels, 2 chopper cycles On-CS1, 1 chopper cycle on the CSs for each grating position, 2 clean ramps per chopper position for 64 and 32 samples per ramp
- Sparsely sampled scan on CS1 (OBCP 27), 100 grating steps with stepsize 20 pixels, 2 chopper cycles CS1-CS2,, 2 clean ramps per chopper position for 64 and 32 samples per ramp
- Others?

10 CQM Related Aspects

WARNING: !!! This section has not yet been updated, but AOT related results from the CQM test can be found in the "PACS CQM-ILT Analysis Report, Part I, II, III" or in the reports on "Testing of Spectroscopy AOT Strategies During CQM ILT" and "Detector Memory/Transient Tests During CQM ILT". **!!!**

The PCD (RD-14) contains precise summaries on the foreseen PACS CQM tests to fulfill the instrument calibration requirements (e.g. page 7ff "PACS CQM test — PCD requirement traceability matrix Spectrometer; Calibration plan for CQM ILT; Sequence of measurements for CQM testing Spectrometer calibration; ...). In addition to the instrument characterisation tests, several AOT related aspects have to be tested.

10.1 Possible AOT related test aspects

Many AOT related aspects can be tested/determined during the CQM test period (or through careful analysis after the CQM). Some aspects might be solved already on sub-unit level tests, e.g. PACS calibration source characterisation, grating and chopper characterisation, detector/readout settings or filter transmission measurements. Simulations will also help to optimise observing and data reduction strategies.

The following AOT related aspects are relevant for the CQM tests:

1. Optimal way to determine responsivity:
   — grating position aspect:
   calibration sequence at a selected grating mid-position (or a small number of well-defined grating positions) or calibration sequence at arbitrary grating positions (scan start/end position; line position; line wavelength±x position) or calibration sequence for each grating position

   How reliable and how comparable are responsivity checks taken at different grating positions? Is there a trend between responsivity values and the total incoming flux (related to the corresponding grating position)?

   — time/stability aspect:
   calibration sequences at beginning/end of operational day and during slews; additionally, calibra-

tion sequences before/after AOT? additionally, calibration sequences after a TBD time period? or a TBD number of chopper cycles or readouts? or a TBD number of grating steps? or for each grating position?

2. Homogeneity aspects (covered by PCD related tests):
   — responsivity checks for different chopper elongations on the PACS calibration sources: Are there inhomogeneity effects due to illumination of the PACS calibration sources? Are there optical distorsions involved?

3. Aspects related to the PACS calibration sources:
   — optimal temperature setting of the PACS calibration sources for a quick and reliable response check during CQM. What are the default starting temperatures of the two PACS calibration sources for a given telescope temperature? In what way can the calibration sources be modified to obtain a faster, higher S/N responsivity value? A concept and test procedure is required to obtain the calibration source settings for ground- and in-orbit conditions.

   — optimal chopper cycles on the PACS calibration sources to determine a quick responsivity check: How many cycles are necessary? Do we need different number of cycles for different grating positions? For different orders?

   — Do the responsivity values change, if we have one OGSE BB at the highest possible flux in the FOV while chopping between the two PACS calibration sources? (The chopper will see one OGSE BB on its path between the 2 PACS calibration sources). Are there straylight influences?

   — Are the isotropy and the homogeneity of the calibration sources sufficient for flat-fielding measurements?

4. Aspects related to the line spectroscopy mode:
   — Characterisation and comparison between measurement of a prominent line with fixed grating position, frequency switching (2 grating positions) and small grating scans. Should the default scan width be zero in line spectroscopy mode (at least for longer wavelengths where the oversampling factor is larger than 1)? SWS and SPIFFI experience shows that zero scan width (very little redundancy) may cause lots of problems.

   — frequency switching vs. on-off chopping for intermediate to strong lines (in orbit also for highly extended line emission)

   — optimal setting of grating positions for frequency switching; influence of grating angles?

5. Aspects related to the range spectroscopy mode:
   — comparison of different resolution spectra (low, intermediate and highest possible resolutions)

   — reset interval aspects:
   one set of reset interval/ integrating capacitor for the full wavelength range of one grating order

will lead to uneven distributions of signal-to-noise ratios within the selected order. Are OBCP modifications required to allow for different settings in range spectroscopy mode? But different settings will then require additional calibration measurements for the ramp characterization.

6. Aspects related to the data rate:
— As default, should we down-link the data which are taken simultaneously in the not-selected order? Or do we only process and downlink the selected wavelengths/order? Do we allow the observer to take this decision?

   — Do we handle line and range spectroscopy in the same way (simultaneously taken range spectroscopy data are probably much more useful than the parallel line data). Do we hope for serendipitous results in the "unwanted" order? See also discussion in Sect. 5.5.

7. Aspects related to the available CQM test period:
— Only a very limited time period is currently foreseen for AOT related tests (currently 5 days). This will strongly influence the selection and sequence of AOT related tests. Relevant AOT information has to be extracted from sub-unit tests and from various other photometer/spectrometer requirement tests during CQM. Specific AOT tests have to be interleaved with other tests for measurement time optimization. A clear sequencing strategy is therefore needed and modifications of already existing calibration implementation and analysis procedures might be necessary.

10.2 Aspects outside CQM

If not otherwise specified, these aspects can most likely only be tested in-orbit.

- satellite pointing modes can not be tested during ILT
- nodding will probably also not be possible when using the hole mask outside the cryostat
- full scans with chopping to the OGSE BBs (temperatures of the OGSE BBs have to be changed for a full scan)
- calibration of the PACS calibration sources on reliable point sources (OGSE BB are extended)
- RSRF determination on flux-calibrated point-sources
- responsivity trends due to high energy particle impacts; responsivity changes and time constants for different glitch rates (to be tested in November 2003 in Belgium)
- ....

A Acronyms

AME	Attitude Measurement Error
AOT	Astronomical Observation Template
APE	Absolute Pointing Error
ARE	Absolute Rate Error
BB	Black Body
CQM	Cryogenic Qualification Model
CRE	Cold/Cryogenic Readout Electronics
CUS	Common Uplink System
DEC/MEC	Detector Control and Mechanism Control (warm electronics)
DMC	DEC/MEC (warm electronics)
DPU	Data Processing Unit (warm electronics)
DTCP	Daily Telecommand Period
FOV	Field of View
FPU	Focal Plane Unit
FWHM	Full Width at Half Maximum
GPR	Grating Position Readback
HIFI	Heterodyne Instrument (of Herschel)
HK	House Keeping
I/F	Interface
IIDR	Instrument Intermediate Design Review, 1.-2. March 2001
ILT	Instrument Level Test
ISO	Infrared Space Observatory, 1995-1998
KUL	Katholieke Universiteit Leuven
LoS	Line of Sight
MPE	Max-Planck-Institut für extraterrestrische Physik, Garching
MPIA	Max-Planck-Institut für Astronomie, Heidelberg
NoP	Number of Parameters
OBCP	On-board Control Procedure
OD	Operational Day
OGSE	Optical Ground Support Equipment
PACS	Photodetector Array Camera and Spectrometer
PCD	PACS Calibration Document
PDE	Pointing Drift Error
PSF	Point-Spread-Function
PUS	Packet Utilisation Standard
RD	Reference Document
RPE	Relative Pointing Error
RSRF	Relative Spectral Response Function
S/N	Signal-to-Noise Ratio
SPIFFI	SPectrograph for Infrared Faint Field Imaging, VLT instrument
SPIRE	Spectral and Photometric Imaging Receiver (of Herschel)
SPU	Signal Processing Unit (warm electronics)
SRPE	Spatial Relative Pointing Error
SSO	Solar system object
SWS	Short Wavelength Spectrometer onboard ISO
TBC	To be checked/confirmed
TBD	To be done/defined
TC	Telecommand
TM	Telemetry
VLT	Very Large Telescope, Paranal, Chile

B PACS Spectrometer description in formulas

The graphical representations of the formulae are given in Figs. 21, 22, 23, 24, 25, 26, 27, 28 and 29. The grating efficiency was calculated by N. Geis ("PCGRATE").

```
alpha: angle of incoming/outgoing beam
n    : grating order [1,2,3]
g    : grating constant 8.50+/-0.05 grooves/mm
lam  : wavelength [micron]
b    : width of grating 320 mm
coll : collimated beam diameter 120 mm
scale: from ray tracing programme, to transfer dispersion to pixels
       =3368 (to obtain 80 km/s/pix at 175 micron)

Littrow grating configuration:
                2 * sin(alpha) = n * g * lam

Angular dispersion:
     delta(alpha) / delta(lam) = n * g / 2 / sqrt(1-(n*g*lam/2)^2)

Maximal resolving power:
              lam / delta(lam) = n * g * b

True grating resolution (replacement of b by the effective projected
collimated beam size) [unitless numbers]:
              lam / delta(lam) = n * g * [coll / cos(alpha)]
                               = n * g * coll / sqrt(1-(n*g*lam/2)^2)

True velocity resolution [km/s]:
          c * delta(lam) / lam = c * sqrt(1-(n*g*lam/2)^2) /
                                 (n * g * coll)

Velocity resolution [km/s] for one pixel (x16 for the 16 pixel array):
 delta(v)/pixel = c / (lam * delta(alpha)/delta(lam) * scale)
                = c * 2 * sqrt(1-(n*g*lam/2)^2) / (lam * n * g * scale)

Effective Resolution [km/s]
       RMS_res = sqrt( (c*delta(lam)/lam)^2 + (delta(v)/pixel)^2)

Oversampling factor
       Oversampling = (c*delta(lam)/lam) / (delta(v)/pixel)

Illuminated Collimator length (in dispersion direction):
       Coll_length = coll / cos(alpha)
```

C Graphical output

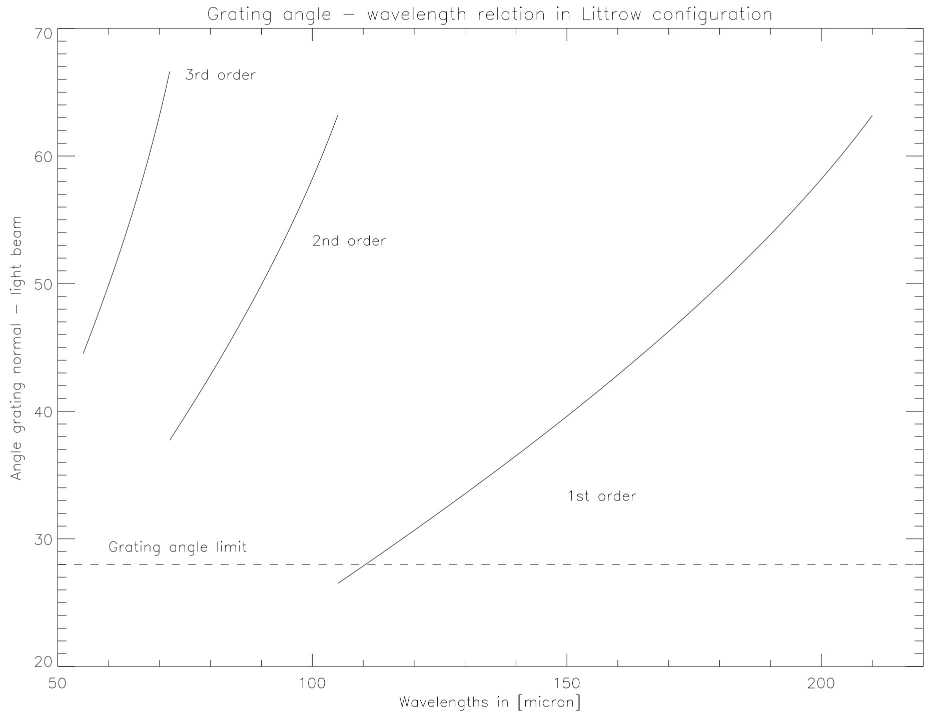

Figure 21: The relation between grating angles and wavelength.

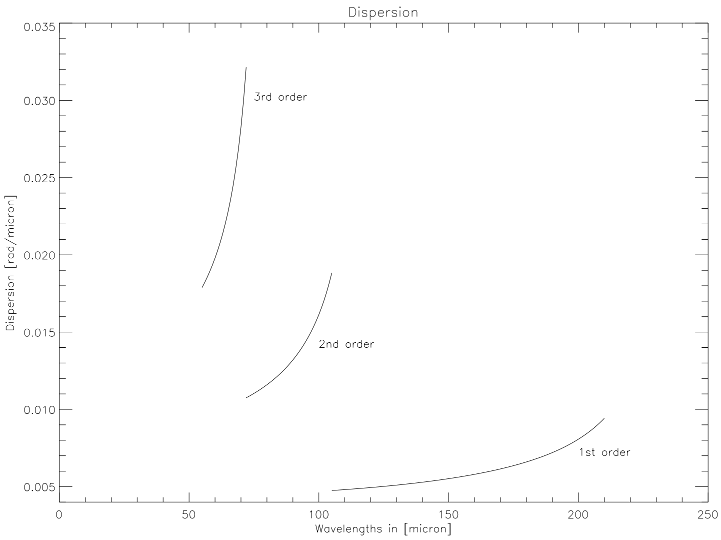

Figure 22: The grating dispersion.

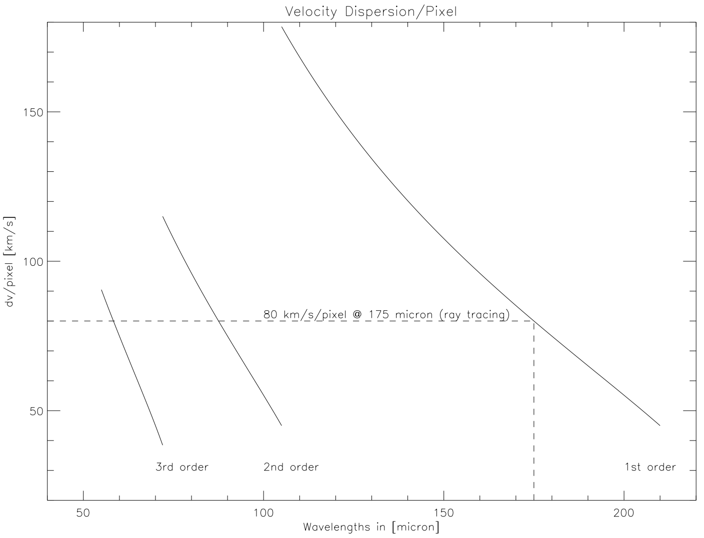

Figure 23: The velocity dispersion per pixel.

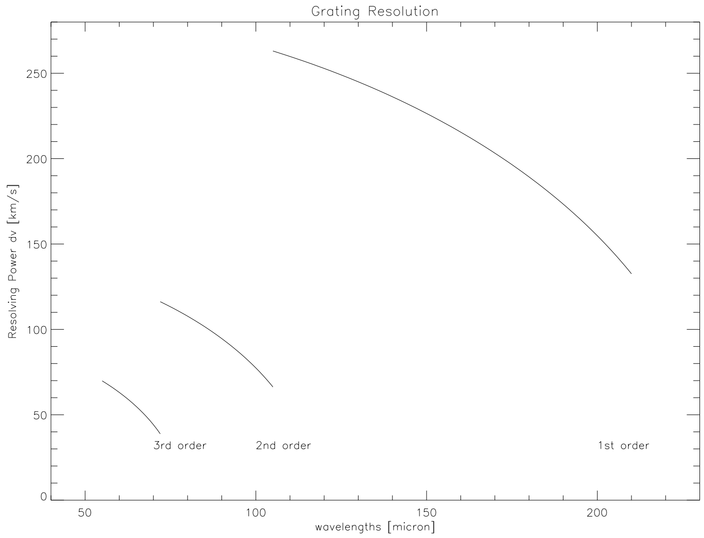

Figure 24: The grating resolution.

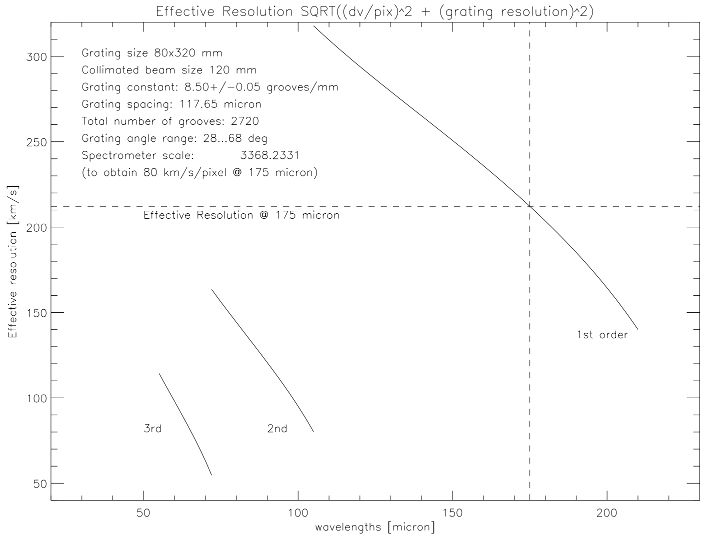

Figure 25: The effective grating resolution.

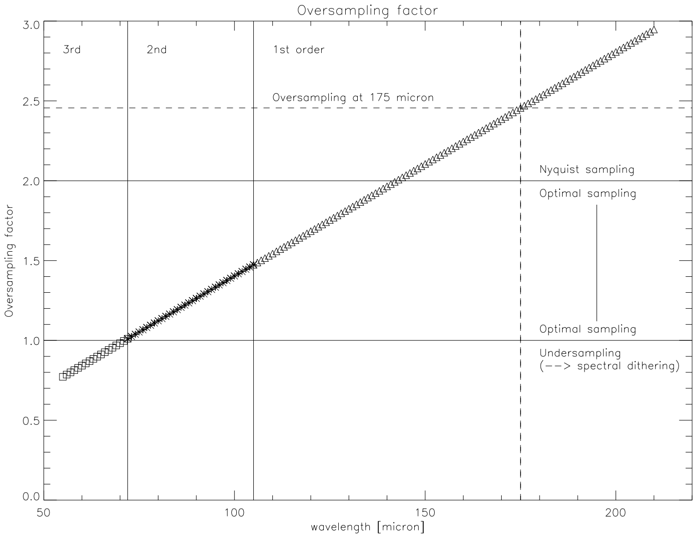

Figure 26: The oversampling factor.

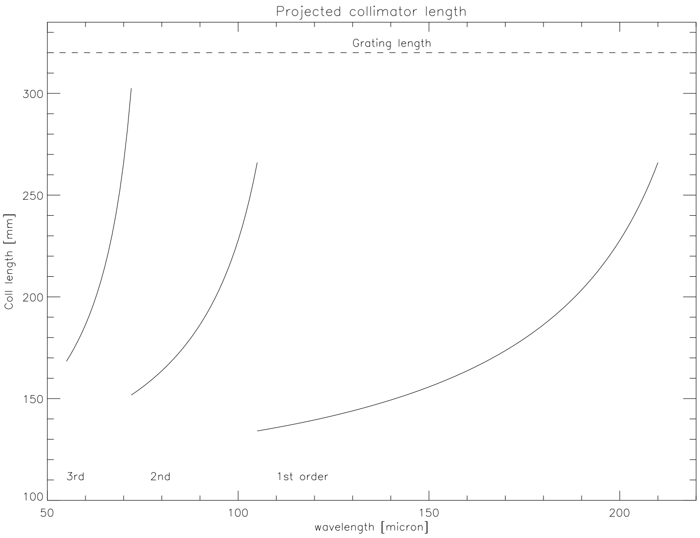

Figure 27: The projected collimator length.

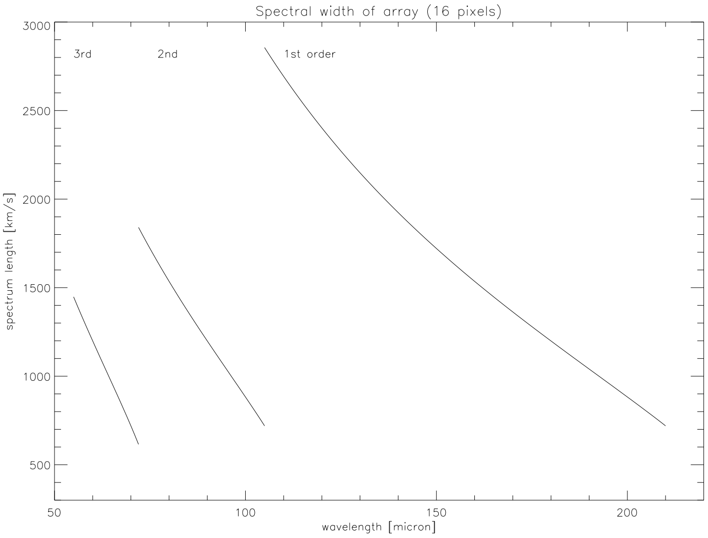

Figure 28: The spectral width of the array.

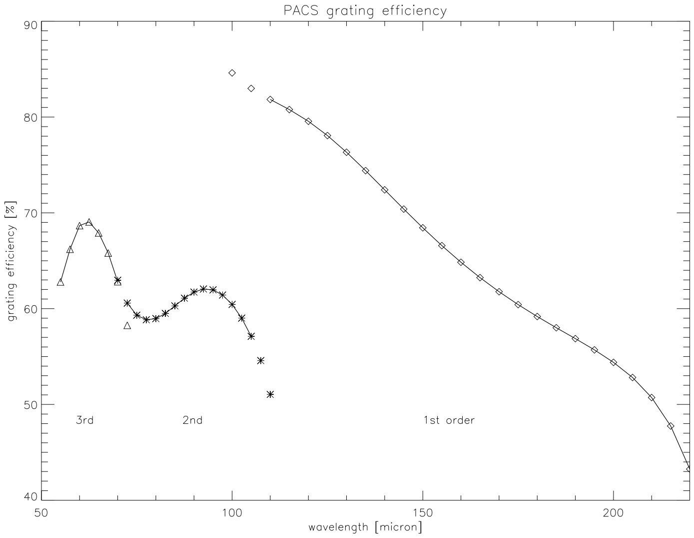

Figure 29: The PACS grating efficiency.

D CUS Cal-U files for Spectroscopy

D.1 Call Tree for PacsLineScan

NOTE: U-CAL files are explicitly shown by name, underneath the module that uses them; main access mode (viz. lookup, interpolate, or bracket) is indicated.

```
PacsLineSpec
    WriteOBSID
    PacsLineSpecProcedure
         SPEC_read_grat_table
             READ_grat_table
                 lookup("GRAT_wave_pos")
         SortProc
         PacsSpecDefaults
             lookup("SPEC_MEC_Defaults")
             lookup("SPEC_CHOP_params")
         PacsLineSpecEstimator
             SPEC_read_grat_table
                 READ_grat_table
                     lookup("GRAT_wave_pos")
             bracket("OBCP8params")
         PacsLineSpecKeyWaves
             SPEC_read_grat_table
                 READ_grat_table
                     lookup("GRAT_wave_pos")
             PacsReadKeyWave
                 lookup("KEY_WAVES")
         RasterRequest (or PointingRequest) with setup time during slew
         PacsLineSpecSlewCal
             SPEC_aot_prologue
                 WriteBBID
                 SPEC_cre_setup
                 SPEC_spu_setup
                 lookup("SPEC_MEC_Defaults")
                 SPEC_MOV_CHOP_and_GRAT
             lookup("SPEC_MEC_Defaults")
             bracket("OBCP13params")
             SPEC_fltw_move
             SPEC_grat_time
             OBCP_chop_grat_scan_cal
                 WriteBBID
                 DMC_chop_grat_scan_cal
             SPEC_fltw_move
```

```
        PacsLineSpecNodding
            PacsLineSpecCommand
                PacsLineSpecFltMove
                    SPEC_fltw_move
                PacsSPECconfChange
                PacsSPECconfSet
                SPEC_grat_time
                OBCP_spec_2_3_chop
                    WriteBBID
                    DMC_spec_2_3_chop
        RasterSlewTime
        PacsLineSpecNoiseRMS
            interpolate("SPECnoise")
        Form_SpecLine_message
            message
    WriteEndID
```

D.2 GRAT_wave_pos

```
#Missionphase  :
#
#  Purpose: Template for the GRAT_wave_pos U-CAl table. This table
#  gives, for a given wavelength, the
#  1- grating order that will be used
#  2- the required operand for the grating position telecommand; to place
#     the required wavelength at the position of pixel 1
#  3- the instantenous bandwidth, expressed in units of grating position, i.e.
#     the required DELTA_grat_pos to shine pixel 16 with the table entry
#     wavelength
#  4- the number of steps to oversample the wavelength space by a factor of 3
#  5- the corresponding step size to explore (3) with (4) steps
#  6- the first column (labeled mkey - as main key) is needed to provide the
#     lookup access key (always the first column).
#  Description   :
#
#  Comments: It is IMPORTANT that the inter-order boundary wavelengths appear
#  twice: as the highest wave of one order and the lowest wave for the lower
#  order. This is due to the table reading logic available in CUS
#
#  History       : 0.1 DAC 3-may-2005 Template created with IDL and
#  TM's formulae. Hopefully, the "true" U-CAL table will have the same
#  layout as this one.
string   double   int   int   int   int   int
mkey   waveLen   order   grat_pos_1   grat_width   nb_step   grat_step
```

```
 0   55.0  3  532036  6568  38  177
 1   56.0  3  507747  6567  38  177
 2   57.0  3  482995  6564  37  182
 3   58.0  3  457743  6561  37  182
 4   59.0  3  431950  6560  37  182
 5   60.0  3  405569  6555  37  182
 6   61.0  3  378548  6551  36  187
 7   62.0  3  350825  6547  36  187
 8   63.0  3  322330  6543  36  186
 9   64.0  3  292979  6538  36  186
10   65.0  3  262676  6534  35  192
11   66.0  3  231302  6528  35  192
12   67.0  3  198721  6519  35  191
13   68.0  3  164751  6514  35  191
14   69.0  3  129180  6506  34  197
15   70.0  3   91727  6494  34  196
16   71.0  3   52017  6485  34  196
17   72.0  3    9549  6469  34  196
18   72.0  2  691512  6498  34  196
19   73.0  2  677007  6497  34  196
20   74.0  2  662377  6495  33  202
21   75.0  2  647615  6494  33  202
22   76.0  2  632715  6493  33  202
23   77.0  2  617672  6492  33  202
24   78.0  2  602480  6490  32  209
25   79.0  2  587132  6489  32  209
26   80.0  2  571621  6487  32  209
27   81.0  2  555940  6486  32  209
28   82.0  2  540081  6484  31  216
29   83.0  2  524035  6482  31  216
30   84.0  2  507793  6481  31  216
31   85.0  2  491345  6479  31  215
32   86.0  2  474681  6477  31  215
33   87.0  2  457789  6475  30  223
34   88.0  2  440657  6473  30  223
35   89.0  2  423271  6471  30  223
36   90.0  2  405616  6467  30  223
37   91.0  2  387677  6466  30  222
38   92.0  2  369435  6464  29  230
39   93.0  2  350872  6461  29  230
40   94.0  2  331967  6457  29  230
41   95.0  2  312692  6455  29  230
42   96.0  2  293025  6452  29  230
43   97.0  2  272935  6449  28  238
```

```
44    98.0   2   252389   6447   28   238
45    99.0   2   231349   6441   28   238
46   100.0   2   209771   6437   28   238
47   101.0   2   187605   6434   28   238
48   102.0   2   164797   6428   27   247
49   103.0   2   141277   6423   27   247
50   104.0   2   116964   6419   27   246
51   105.0   2    91770   6412   27   246
52   105.0   1   955330   6779   27   260
53   108.0   1   936143   6778   26   271
54   111.0   1   916811   6776   26   271
55   114.0   1   897328   6774   25   282
56   117.0   1   877685   6773   25   282
57   120.0   1   857874   6772   25   282
58   123.0   1   837886   6770   24   294
59   126.0   1   817713   6768   24   294
60   129.0   1   797342   6767   23   307
61   132.0   1   776765   6765   23   307
62   135.0   1   755969   6763   22   322
63   138.0   1   734942   6762   22   322
64   141.0   1   713671   6759   22   321
65   144.0   1   692142   6758   21   337
66   147.0   1   670339   6756   21   337
67   150.0   1   648244   6755   21   337
68   153.0   1   625842   6752   20   355
69   156.0   1   603110   6750   20   355
70   159.0   1   580028   6747   20   355
71   162.0   1   556571   6745   19   374
72   165.0   1   532712   6742   19   374
73   168.0   1   508423   6740   19   374
74   171.0   1   483671   6737   18   396
75   174.0   1   458420   6734   18   396
76   177.0   1   432627   6731   18   395
77   180.0   1   406246   6727   18   395
78   183.0   1   379225   6723   17   420
79   186.0   1   351502   6720   17   420
80   189.0   1   323007   6715   17   419
81   192.0   1   293656   6711   17   419
82   195.0   1   263352   6705   16   447
83   198.0   1   231980   6699   16   446
84   201.0   1   199397   6693   16   446
85   204.0   1   165428   6685   16   445
86   207.0   1   129857   6677   16   445
87   210.0   1    92402   6667   15   476
```

D.3 KEY_WAVES

```
# Missionphase  : Operations
# Purpose       : List KeyWavelengths to be used with a given order
# Description   : This Table is used to generate a list of KeyWaves from a
#                 list of UserWaves
# History       : 0.1  8-Jun-2005 DAC
# Comments      : Acces key is grating order. Each row contains nWAVE KeyWave
#                 values (unused COLs are 0.0 filled)
# Identification of COLs
# order nWAVE  KeyWave1  KeyWave2  KeyWave3  KeyWave4  KeyWave5  KeyWave6
string   int   double   double   double   double   double   double
order   nWAVE   KeyWave1   KeyWave2   KeyWave3   KeyWave4   KeyWave5   KeyWave6
3   4    55.0    58.0    62.7    69.0     0.0     0.0
2   4    74.0    82.5    87.0    94.0     0.0     0.0
1   6   110.0   130.0   148.0   165.0   174.0   188.0
```

D.4 OBCP13params

```
# Missionphase  : Operations
# Purpose       : OBCP#13 parameters used for SLEW calibration
# Description   : U-CAL plain ASCII table
# History       : 0.1  1-Jun-2005 DAC
#                 0.2  3-Jun-2005 DAC New params as per TM's suggestion
# Comments      : Acces key is wavelength
# Identification of COLs and parameters P#1, P#2, etc. Note that abs(P#9) is assumed equal to P
# wave  order    P#1                    P#2       P#4       P#5      P#3          P#7     P#6
double   int   int   int   int   int   int   int   int   int   int
wave   ord   nb_up_dn   grat_start   grat_coarse   grat_fine   nb_cycles   nb_steps   nb_ramps_
 55.0   3   1   535000   0   400   1   16   4   -25000   25000
 58.0   3   1   461000   0   400   1   16   4   -25000   25000
 62.7   3   1   335000   0   400   1   16   4   -25000   25000
 69.0   3   1   132000   0   400   1   16   4   -25000   25000
 74.0   2   1   666000   0   400   1   16   4   -25000   25000
 82.5   2   1   535000   0   400   1   16   4   -25000   25000
 87.0   2   1   461000   0   400   1   16   4   -25000   25000
 94.0   2   1   335000   0   400   1   16   4   -25000   25000
110.0   1   1   927000   0   400   1   16   4   -25000   25000
130.0   1   1   794000   0   400   1   16   4   -25000   25000
148.0   1   1   666000   0   400   1   16   4   -25000   25000
165.0   1   1   535000   0   400   1   16   4   -25000   25000
174.0   1   1   461000   0   400   1   16   4   -25000   25000
188.0   1   1   335000   0   400   1   16   4   -25000   25000
```

D.5 OBCP27RANGEparams

```
# Missionphase  : Operations
# Purpose       : Predetermined values for confOBCP data structure
# Comments      : Follows (almost) column by column contents of confOBCP
#                 The column "duree" gives the approxiamte duration PER
#                 line and PER raster point. Based on 1000 grating steps per
#                 line; AOT code uses actual nb_grat_steps and scales entry
#                 accordingly
# History       : 0.1 22-jun-2005 DAC
double   int   int   int   int   int
duree   nb_nods   nb_up_down   nb_SRC_OFF   nb_ramps_plateau   nb_CS1_CS2
 1500.0   0   1   1   1   0
 2000.0   0   1   1   2   0
 2500.0   0   1   1   3   0
 3000.0   0   1   1   4   0
 3500.0   0   1   1   5   0
 4000.0   0   1   1   6   0
 4500.0   0   1   4   1   0
 4500.0   0   3   1   1   0
 4500.0   0   1   2   3   0
 4500.0   0   1   1   7   0
 5000.0   0   2   2   1   0
 5000.0   0   1   3   2   0
 5000.0   0   2   1   3   0
 5000.0   0   1   1   8   0
 5500.0   0   1   5   1   0
 5500.0   0   1   2   4   0
 6000.0   0   3   1   2   0
 6000.0   0   2   1   4   0
 6500.0   0   1   4   2   0
 6500.0   0   1   3   3   0
 6500.0   0   1   2   5   0
 7000.0   0   2   3   1   0
 7000.0   0   2   2   2   0
 7000.0   0   2   1   5   0
 7500.0   0   3   2   1   0
 7500.0   0   3   1   3   0
 7500.0   0   1   2   6   0
 8000.0   0   1   5   2   0
 8000.0   0   1   3   4   0
 8000.0   0   2   1   6   0
 8500.0   0   1   4   3   0
 8500.0   0   1   2   7   0
```

```
 9000.0   0   2   4   1   0
 9000.0   0   2   2   3   0
 9000.0   0   3   1   4   0
 9000.0   0   2   1   7   0
 9500.0   0   1   3   5   0
 9500.0   0   1   2   8   0
10000.0   0   2   3   2   0
10000.0   0   2   1   8   0
10500.0   0   3   3   1   0
10500.0   0   3   2   2   0
10500.0   0   1   5   3   0
10500.0   0   1   4   4   0
10500.0   0   3   1   5   0
11000.0   0   2   5   1   0
11000.0   0   2   2   4   0
11000.0   0   1   3   6   0
12000.0   0   3   1   6   0
12500.0   0   1   4   5   0
12500.0   0   1   3   7   0
13000.0   0   2   4   2   0
13000.0   0   2   3   3   0
13000.0   0   1   5   4   0
13000.0   0   2   2   5   0
13500.0   0   3   4   1   0
13500.0   0   3   2   3   0
13500.0   0   3   1   7   0
14000.0   0   1   3   8   0
14500.0   0   1   4   6   0
15000.0   0   3   3   2   0
15000.0   0   2   2   6   0
15000.0   0   3   1   8   0
15500.0   0   1   5   5   0
16000.0   0   2   5   2   0
16000.0   0   2   3   4   0
16500.0   0   3   5   1   0
16500.0   0   3   2   4   0
16500.0   0   1   4   7   0
17000.0   0   2   4   3   0
17000.0   0   2   2   7   0
18000.0   0   1   5   6   0
18500.0   0   1   4   8   0
19000.0   0   2   3   5   0
19000.0   0   2   2   8   0
19500.0   0   3   4   2   0
```

```
19500.0   0   3   3   3   0
19500.0   0   3   2   5   0
20500.0   0   1   5   7   0
21000.0   0   2   5   3   0
21000.0   0   2   4   4   0
22000.0   0   2   3   6   0
22500.0   0   3   2   6   0
23000.0   0   1   5   8   0
24000.0   0   3   5   2   0
24000.0   0   3   3   4   0
25000.0   0   2   4   5   0
25000.0   0   2   3   7   0
25500.0   0   3   4   3   0
25500.0   0   3   2   7   0
26000.0   0   2   5   4   0
28000.0   0   2   3   8   0
28500.0   0   3   3   5   0
28500.0   0   3   2   8   0
29000.0   0   2   4   6   0
31000.0   0   2   5   5   0
31500.0   0   3   5   3   0
31500.0   0   3   4   4   0
33000.0   0   3   3   6   0
33000.0   0   2   4   7   0
36000.0   0   2   5   6   0
37000.0   0   2   4   8   0
37500.0   0   3   4   5   0
37500.0   0   3   3   7   0
39000.0   0   3   5   4   0
41000.0   0   2   5   7   0
42000.0   0   3   3   8   0
43500.0   0   3   4   6   0
46000.0   0   2   5   8   0
46500.0   0   3   5   5   0
49500.0   0   3   4   7   0
54000.0   0   3   5   6   0
55500.0   0   3   4   8   0
61500.0   0   3   5   7   0
69000.0   0   3   5   8   0
```

D.6 OBCP27SEDparams

```
# Missionphase  : Operations
# Purpose       : Predetermined values for confOBCP data structure
```

```
# Comments      : Follows (almost) column by column contents of confOBCP
#                 The column "duree" has no meaning for this file (other
#                 than being used to access a particular row). Future
#                 versions could have more rows, some parameter being
#                 different from row to row
# History       : 0.1 22-jun-2005 DAC
double   int   int   int   int   int
duree   nb_nods   nb_up_down   nb_SRC_OFF   nb_ramps_plateau   nb_CS1_CS2
1000.0   0   1   1   1   0
```

D.7 OBCP8params

```
# Missionphase  : Operations
# Purpose       : Predetermined values for confOBCP data structure
# Comments      : Follows (almost) column by column contents of confOBCP
#                 The column "duree" gives the approxiamte duration PER
#                 line and PER raster point.
# History       : 0.1 31-may-2005 DAC
#                 0.2 13-jun-2005 Added nb_nods
double   int   int   int   int   int
duree   nb_nods   nb_up_down   nb_SRC_OFF   nb_ramps_plateau   nb_CS1_CS2
  316.0   1   1   1   1   0
  456.0   1   1   1   2   0
  596.0   1   1   2   1   0
  596.0   1   1   1   3   0
  631.0   1   2   1   1   0
  736.0   1   1   1   4   0
  876.0   1   1   3   1   0
  876.0   1   1   2   2   0
  876.0   1   1   1   5   0
  911.0   1   2   1   2   0
  946.0   1   3   1   1   0
 1016.0   1   1   1   6   0
 1156.0   1   1   4   1   0
 1156.0   1   1   2   3   0
 1156.0   1   1   1   7   0
 1191.0   1   2   2   1   0
 1191.0   1   2   1   3   0
 1296.0   1   1   3   2   0
 1296.0   1   1   1   8   0
 1366.0   1   3   1   2   0
 1436.0   1   1   5   1   0
 1436.0   1   1   2   4   0
 1471.0   1   2   1   4   0
```

```
1716.0   1   1   4   2   0
1716.0   1   1   3   3   0
1716.0   1   1   2   5   0
1751.0   1   2   3   1   0
1751.0   1   2   2   2   0
1751.0   1   2   1   5   0
1786.0   1   3   2   1   0
1786.0   1   3   1   3   0
1996.0   1   1   2   6   0
2031.0   1   2   1   6   0
2136.0   1   1   5   2   0
2136.0   1   1   3   4   0
2206.0   1   3   1   4   0
2276.0   1   1   4   3   0
2276.0   1   1   2   7   0
2311.0   1   2   4   1   0
2311.0   1   2   2   3   0
2311.0   1   2   1   7   0
2556.0   1   1   3   5   0
2556.0   1   1   2   8   0
2591.0   1   2   3   2   0
2591.0   1   2   1   8   0
2626.0   1   3   3   1   0
2626.0   1   3   2   2   0
2626.0   1   3   1   5   0
2836.0   1   1   5   3   0
2836.0   1   1   4   4   0
2871.0   1   2   5   1   0
2871.0   1   2   2   4   0
2976.0   1   1   3   6   0
3046.0   1   3   1   6   0
3396.0   1   1   4   5   0
3396.0   1   1   3   7   0
3431.0   1   2   4   2   0
3431.0   1   2   3   3   0
3431.0   1   2   2   5   0
3466.0   1   3   4   1   0
3466.0   1   3   2   3   0
3466.0   1   3   1   7   0
3536.0   1   1   5   4   0
3816.0   1   1   3   8   0
3886.0   1   3   3   2   0
3886.0   1   3   1   8   0
3956.0   1   1   4   6   0
```

```
 3991.0   1   2   2   6   0
 4236.0   1   1   5   5   0
 4271.0   1   2   5   2   0
 4271.0   1   2   3   4   0
 4306.0   1   3   5   1   0
 4306.0   1   3   2   4   0
 4516.0   1   1   4   7   0
 4551.0   1   2   4   3   0
 4551.0   1   2   2   7   0
 4936.0   1   1   5   6   0
 5076.0   1   1   4   8   0
 5111.0   1   2   3   5   0
 5111.0   1   2   2   8   0
 5146.0   1   3   4   2   0
 5146.0   1   3   3   3   0
 5146.0   1   3   2   5   0
 5636.0   1   1   5   7   0
 5671.0   1   2   5   3   0
 5671.0   1   2   4   4   0
 5951.0   1   2   3   6   0
 5986.0   1   3   2   6   0
 6336.0   1   1   5   8   0
 6406.0   1   3   5   2   0
 6406.0   1   3   3   4   0
 6791.0   1   2   4   5   0
 6791.0   1   2   3   7   0
 6826.0   1   3   4   3   0
 6826.0   1   3   2   7   0
 7071.0   1   2   5   4   0
 7631.0   1   2   3   8   0
 7666.0   1   3   3   5   0
 7666.0   1   3   2   8   0
 7911.0   1   2   4   6   0
 8471.0   1   2   5   5   0
 8506.0   1   3   5   3   0
 8506.0   1   3   4   4   0
 8926.0   1   3   3   6   0
 9031.0   1   2   4   7   0
 9871.0   1   2   5   6   0
10151.0   1   2   4   8   0
10186.0   1   3   4   5   0
10186.0   1   3   3   7   0
10606.0   1   3   5   4   0
11271.0   1   2   5   7   0
```

```
11446.0   1   3   3   8   0
11866.0   1   3   4   6   0
12671.0   1   2   5   8   0
12706.0   1   3   5   5   0
13546.0   1   3   4   7   0
14806.0   1   3   5   6   0
15226.0   1   3   4   8   0
16906.0   1   3   5   7   0
19006.0   1   3   5   8   0
```

D.8 PACSparams

```
# Missionphase  :
#
# Purpose       : Useful PACS parameter "database" containing data
#                 needed to compute several bolo and spectro time
#                 related parameters (ramp duration, bolo integration, etc)
#                 Also duration of "internal" DEC/MEC commands
#                 Most entries here are supposed not to change over
#                 the mission but one never knows...
#
# Author        : Diego A. Cesarsky
# CVS file      : PACSparams
# Description   : Plain ASCII table
#
# Comments      : Entries here are mostly used by CUS to perform
#                 time related computations
#
# Version : 0.1  6-Oct-2004 DAC
# History : 0.2 11-Oct-2004 Renamed row "photo_sample" to
#                           "spec_sample"
#           0.3 20-apr-2005 DAC Added row for either fltw move time
#           0.4 26-apr-2005 DAC Added row for grating move time
# Start of Table:
string         double   string
parameter   freq_time   unit
bolo_sample      20.0   Hz
spec_sample     256.0   Hz
int_cmd         200.0   msec
dmc_margin     2500.0   msec
obcp_margin    1000.0   msec
fltw_time     15000.0   msec
grat_time     10000.0   msec
```

D.9 SPEC_BAND_params

```
# Missionphase  :
#
# Purpose       : Define band limits for spectroscopy; associated
#                 U-CAL file (grating position, RSRF, etc.), and
#                 lo, med, and hi resolution grating steps
# Author        : H. Feuchtgruber
# CVS file      : SPEC_BAND_params
# Description   : Holds PACS wavelength band limits for use
#                 by spectroscopy AOTs
# Comments      :
# Version : 1.1
# History : 1.0 12-Apr-2005 HF initial version
#           1.1 13-Apr-2005 HF, allow for overlap
#           1.2 21-jun-2005 DAC Add pointer to CAL_FILE for grat_pos;
#                               indexed by ORDER; merged contents of
#                               HF's Band_Steps CAL file
#           1.3 23-jun-2005 Introduce ORDER=4 (1 and 2) and 5
#                          (1 and 3) for use in the "SED" mode
# Successive columns indicate:
# blue_edge red_edge low_resol medium_resol high_resol FWHM  Grat_pos_FILE
# Start of Table:
string   double   double   int     int    int   int   string
ORDER    BLU       RED     low   medium   high   FWHM   CAL_FILE
1        104.9     200.0    352    176     88    709   SPEC_RSRF_Red
2         71.9     105.1    284    142     71    567   SPEC_RSRF_Blue_LW
3         54.0      72.1    252    126     63    504   SPEC_RSRF_Blue_SW
4         70.0     210.0   3600   2400   1200    567   SPEC_RANGE_params
5         54.0      72.0   3750   2500   1250    504   SPEC_RANGE_params
```

D.10 SPEC_CHOP_params

```
# Missionphase: Operations
# Purpose: Gives chopper SRC, REF1, and REF2 based on HSPOT choice
#
# Description: Chopper throw parameters indexed by HSPOT's
# string throw = "large" in ["large", "medium", "small"]
# Comments      :
# History       : 0.1 14-jun-2005 DAC
string   int   int   int
throw    SRC   REF1   REF2
small      0   1000   -1000
medium     0   2000   -2000
```

```
large     0   3000   -3000
```

D.11 SPEC_MEC_Defaults

```
# Missionphase  :
#
# Purpose       : Mechanisms default settings
#
# Author        : H. Feuchtgruber
# CVS file      :
# Description   : Holds default positions for FWs, grating
#                 and chopper
# Comments      :
# Version : 1.0 22-Apr-2005 HF initial version
# History : 1.1  7-Jun-2005 SPEC filter position is expressed in order
#
# Start of Table:
string   int   int   int   double   double
parameter   chopper   grating   FW   CS1   CS2
Spectroscopy   0   535000   3   80.0   92.0
Photometry     0   535000   3   80.0   92.0
```

D.12 SPEC_RANGE_params

```
# FileName     : SPEC_RANGE_params
# Missionphase : Operations
# Purpose      : Pre-defined wavelength ranges for "SED" mode of SpecRange AOT
# Author       : DAC
# Description  : Holds wavelength ranges, several sampling resolutions, names
#                of grating calibration CAL files. A "SED" observation will
#                perform 1st row and then 2nd row.
# Comments     : Range limits are given here as grat_pos; ORDER 1 is not
#                mentioned because it is always present. The grat_pos for
#                ORDER = 2 are those needed for a ful scan of ORDER = 1. From
#                grat_pos 977546 to 723197, ORDER=2 will see no signal.
#                NOTE: ORDERs 12 and 13 defined in SPEC_BAND_params
# Version : 0.1 DAC 22-jun-2005
# History :
# Successive columns indicate (access by COL1: SED range number
# COL 2         : the ORDER used to command the FLTW
# COL 3 and 4   : blue and red edges of grat_pos
# COL 5, 6 and 7: step size for ExtraFAST, FAST and SLOW range scans
# COL 8         : FWHM  to estimate over/under sampling factor
string   int   double   double   int   int   int   int
```

```
SED   ORDER   BLU   RED   EFAST   FAST   SLOW   FWHM
1   2   977546.0   94771.0   3600   2400   1200   504
2   3   535100.0   12574.0   3750   2500   1250   567
```

D.13 SPEC_RSRF_Blue_LW

```
# Missionphase  :
# Purpose       : Uplink RSRF and grating calibration blue lw
#                 spectrometer
# CVS file      : SPEC_RSRF_Blue_LW
# Description   : Holds PACS grating wavelength calibration and
#                 relative spectral response for the blue lw
#                 spectrometer
# Comments      : Grating is used in ORDER = 2
# Version : 1.0  18-Apr-2005 HF initial version
# History : 1.1 21-jun-2005 DAC Placed WaveLength in COL 1
# Start of Table:
double   double   double
lambda   grat_pos   blue_lw_rsrf
 65.0   792916.0   0.0
 66.0   779174.0   0.0
 67.0   765335.0   0.0
 68.0   751395.0   0.0
 69.0   737350.0   0.0
 70.0   723197.0   0.22752787
 71.0   708931.0   0.29066244
 72.0   694548.0   0.3958698
 73.0   680044.0   0.55275827
 74.0   665412.0   0.6948805
 75.0   650649.0   0.70159407
 76.0   635749.0   0.58606599
 77.0   620706.0   0.54121697
 78.0   605513.0   0.803162
 79.0   590164.0   0.93744333
 80.0   574653.0   0.97022294
 81.0   558971.0   0.97738109
 82.0   543112.0   0.99069269
 83.0   527065.0   0.99553563
 84.0   510822.0   0.96863566
 85.0   494374.0   0.92736343
 86.0   477709.0   0.87167746
 87.0   460816.0   0.84074574
 88.0   443683.0   0.83369624
 89.0   426296.0   0.85053847
```

```
 90.0   408640.0   0.84307947
 91.0   390700.0   0.84871286
 92.0   372457.0   0.81458799
 93.0   353892.0   0.83278034
 94.0   334985.0   0.80213671
 95.0   315711.0   0.71305697
 96.0   296043.0   0.71250008
 97.0   275951.0   0.67955485
 98.0   255404.0   0.51089612
 99.0   234362.0   0.46160933
100.0   212782.0   0.34732413
101.0   190616.0   0.30342371
102.0   167805.0   0.19818751
103.0   144282.0   0.10101746
104.0   119969.0   0.046668501
105.0    94771.2   0.0
106.0    68574.0   0.0
107.0    41236.6   0.0
108.0    12582.0   0.0
109.0   -17615.1   0.0
110.0   -49653.8   0.0
111.0   -83941.2   0.0
```

D.14 SPEC_RSRF_Blue_SW

```
# Missionphase  :
# Purpose       : Uplink RSRF and grating calibration blue sw
#                 spectrometer
# CVS file      : SPEC_RSRF_Blue_SW
# Description   : Holds PACS grating wavelength calibration and
#                 relative spectral response for the blue sw
#                 spectrometer
# Comments      : Grating is used in ORDER = 3
# Version : 1.0 18-Apr-2005 HF initial version
# History : 1.1 21-jun-2005 DAC Placed WaveLength in COL1
# Start of Table:
double         double            double
lambda       grat_pos      blue_sw_rsrf
 50.0000        650641.        0.000000
 51.0000        628237.        0.000000
 52.0000        605504.        0.000000
 53.0000        582421.        0.000000
 54.0000        558963.        0.170310
 55.0000        535103.        0.337244
```

```
 56.0000       510813.       0.339891
 57.0000       486060.       0.555918
 58.0000       460807.       0.528813
 59.0000       435013.       0.606168
 60.0000       408631.       0.686233
 61.0000       381608.       0.841859
 62.0000       353884.       0.908120
 63.0000       325387.       0.980722
 64.0000       296034.       0.977937
 65.0000       265728.       0.926116
 66.0000       234353.       0.862504
 67.0000       201767.       0.810907
 68.0000       167796.       0.752086
 69.0000       132222.       0.724864
 70.0000        94763.0      0.621120
 71.0000        55049.2      0.000000
 72.0000        12573.5      0.000000
 73.0000       -33390.5      0.000000
 74.0000       -83949.7      0.000000
 75.0000      -140946.       0.000000
# End of Table
```

D.15 SPEC_RSRF_Red

```
# Missionphase  :
# Purpose       : Uplink RSRF and grating calibration red
#                 spectrometer
# CVS file      : SPEC_RSRF_Red
# Description   : Holds PACS grating wavelength calibration and
#                 relative spectral response for the red
#                 spectrometer
# Comments      : Grating is used in ORDER = 1
# Version : 1.0 18-Apr-2005 HF initial version
# History : 1.1 21-jun-2005 DAC Placed WaveLength in COL 1
# Start of Table:
double   double   double
lambda   grat_pos   red_rsrf
 50.0   1291710.0   0.0
 51.0   1285870.0   0.0
 52.0   1280030.0   0.0
 53.0   1274190.0   0.0
 54.0   1268340.0   0.0
 55.0   1262480.0   0.0
 56.0   1256610.0   0.0
```

```
 57.0   1250740.0   0.0
 58.0   1244870.0   0.0
 59.0   1238980.0   0.0
 60.0   1233090.0   0.0
 61.0 1227200.0   0.0
 62.0 1221290.0   0.0
 63.0 1215380.0   0.0
 64.0 1209460.0   0.0
 65.0 1203540.0   0.0
 66.0 1197600.0   0.0
 67.0 1191660.0   0.0
 68.0 1185710.0   0.0
 69.0 1179750.0   0.0
 70.0 1173790.0   0.0
 71.0 1167820.0   0.0
 72.0 1161830.0   0.0
 73.0 1155840.0   0.0
 74.0 1149840.0   0.0
 75.0 1143830.0   0.0
 76.0 1137810.0   0.0
 77.0 1131790.0   0.0
 78.0 1125750.0   0.0
 79.0 1119700.0   0.0
 80.0 1113650.0   0.0
 81.0 1107580.0   0.0
 82.0 1101510.0   0.0
 83.0 1095420.0   0.0
 84.0 1089320.0   0.0
 85.0 1083210.0   0.0
 86.0 1077090.0   0.0
 87.0 1070960.0   0.0
 88.0 1064820.0   0.0
 89.0 1058670.0   0.0
 90.0 1052510.0   0.0
 91.0 1046330.0   0.0
 92.0 1040140.0   0.0
 93.0 1033940.0   0.0
 94.0 1027730.0   0.0
 95.0 1021500.0   0.0
 96.0 1015260.0   0.0
 97.0 1009010.0   0.0
 98.0 1002740.0   0.0
 99.0  996466.0   0.0
100.0    990174.0   0.0
```

101.0	983867.0	0.0
102.0	977546.0	0.3425497
103.0	971211.0	0.46361387
104.0	964861.0	0.5609388
105.0	958496.0	0.60987517
106.0	952116.0	0.61293614
107.0	945720.0	0.65174514
108.0	939308.0	0.69263352
109.0	932881.0	0.70977126
110.0	926437.0	0.70732868
111.0	919976.0	0.72201613
112.0	913499.0	0.73998197
113.0	907004.0	0.7631781
114.0	900492.0	0.79475322
115.0	893963.0	0.82262023
116.0	887415.0	0.82454898
117.0	880849.0	0.8506819
118.0	874264.0	0.84562404
119.0	867661.0	0.87202685
120.0	861038.0	0.87043321
121.0	854395.0	0.90173817
122.0	847732.0	0.91176133
123.0	841049.0	0.94597254
124.0	834345.0	0.92882621
125.0	827621.0	0.95733875
126.0	820875.0	0.97562352
127.0	814107.0	0.9893174
128.0	807316.0	0.96578334
129.0	800504.0	0.96964858
130.0	793668.0	0.93448553
131.0	786809.0	0.95115673
132.0	779926.0	0.94146787
133.0	773018.0	0.93791865
134.0	766086.0	0.96909651
135.0	759129.0	0.97341398
136.0	752146.0	0.97139308
137.0	745137.0	0.96917282
138.0	738102.0	0.96959013
139.0	731039.0	0.98190181
140.0	723948.0	0.98109588
141.0	716830.0	0.98725171
142.0	709683.0	0.9603027
143.0	702506.0	0.95391498
144.0	695300.0	0.99152675

```
145.0   688063.0   0.93867425
146.0   680795.0   0.95379877
147.0   673496.0   0.95736446
148.0   666164.0   0.9343315
149.0   658799.0   0.92891672
150.0   651401.0   0.91905837
151.0   643968.0   0.91051716
152.0   636501.0   0.88702702
153.0   628997.0   0.88720825
154.0   621457.0   0.89767772
155.0   613880.0   0.83968934
156.0   606265.0   0.86078085
157.0   598610.0   0.84685883
158.0   590916.0   0.82227112
159.0   583181.0   0.81897466
160.0   575405.0   0.79484374
161.0   567586.0   0.80705269
162.0   559723.0   0.77415375
163.0   551816.0   0.76360924
164.0   543863.0   0.7412218
165.0   535864.0   0.72817206
166.0   527817.0   0.69558786
167.0   519720.0   0.70926134
168.0   511574.0   0.70449363
169.0   503376.0   0.6655682
170.0   495125.0   0.66507957
171.0   486821.0   0.65697392
172.0   478460.0   0.64400406
173.0   470043.0   0.65166124
174.0   461568.0   0.63508883
175.0   453032.0   0.62185594
176.0   444434.0   0.61756291
177.0   435773.0   0.58757008
178.0   427047.0   0.59838314
179.0   418254.0   0.58098834
180.0   409392.0   0.56747729
181.0   400458.0   0.53571824
182.0   391451.0   0.53308434
183.0   382369.0   0.52184941
184.0   373209.0   0.51538036
185.0   363968.0   0.48297841
186.0   354644.0   0.46908954
187.0   345235.0   0.46146555
188.0   335737.0   0.41743552
```

```
189.0    326147.0   0.40015893
190.0    316462.0   0.38486827
191.0    306679.0   0.3386684
192.0    296794.0   0.31535873
193.0    286804.0   0.3012052
194.0    276703.0   0.26478814
195.0    266489.0   0.24206211
196.0    256156.0   0.20989434
197.0    245699.0   0.19441361
198.0    235114.0   0.17877767
199.0    224394.0   0.15898381
200.0    213534.0   0.15705644
201.0    202528.0   0.1499313
202.0    191368.0   0.15300613
203.0    180047.0   0.16608251
204.0    168557.0   0.18462347
205.0    156889.0   0.19947251
206.0    145034.0   0.22194697
207.0    132982.0   0.24076636
208.0    120721.0   0.25030999
209.0    108240.0   0.29007491
210.0     95523.2   0.0
211.0     82557.6   0.0
212.0     69326.0   0.0
213.0     55809.7   0.0
214.0     41988.4   0.0
215.0     27838.5   0.0
216.0     13334.2   0.0
217.0     -1554.98  0.0
218.0    -16863.0   0.0
219.0    -32629.6   0.0
220.0    -48901.7   0.0
```

D.16 SPECnoise

```
# Missionphase  : Operations
# Purpose       : Estimate SPEC noise fluctuations
# Description   : Taken from DL's Guesstimator
# Comments      : Gives RMS noise [Jy] for 1 [sec] integration time
# Verbatim from DL's Guesstimator
#     Spectroscopic sensitivity is given in two arrays for wavelength in micron
#     (senswave), and sensitivity (sensflux) given as the flux density in Jy for
#     which S/N 1 is obtained in 1 sec for one resolution element, assuming
#     an observing mode where the line is always seen on some detector but excluding
```

```
#     the noise from background subtraction. The large overheads account for chopping.
# History       : 0.1 2-Jun-2005 DAC
double   double
wave   noiseRMS
 55.0   3.3
 60.0   3.16
 65.0   3.32
 70.0   3.81
 71.9   3.82
 72.0   2.18
 75.0   2.23
 80.0   2.26
 90.0   2.21
100.0   2.41
104.9   2.37
105.0   1.23
110.0   1.27
120.0   1.33
140.0   1.45
160.0   1.76
180.0   2.41
200.0   4.06
210.0   8.26
```

E CQM chopper calibration by Zeiss

Table 7: QM chopper calibration by Zeiss (see also Tbl. 1 and Fig. 4).

FP1 [V]	FP2 [V]	angle [deg]
-6.093	-5.440	-11.17
-6.021	-5.364	-10.88
-5.942	-5.281	-10.59
-5.855	-5.194	-10.29
-5.762	-5.101	-9.98
-5.663	-5.004	-9.69
-5.557	-4.901	-9.39
-5.445	-4.793	-9.08
-5.328	-4.679	-8.78
-5.202	-4.561	-8.48
-5.074	-4.438	-8.18
-4.937	-4.309	-7.87
-4.799	-4.175	-7.56
-4.654	-4.035	-7.25
-4.506	-3.895	-6.93
-4.350	-3.744	-6.63
-4.194	-3.592	-6.30
-4.029	-3.432	-5.99
-3.865	-3.269	-5.67
-3.692	-3.100	-5.36
-3.518	-2.929	-5.04
-3.337	-2.748	-4.73
-3.155	-2.565	-4.41
-2.965	-2.382	-4.09
-2.771	-2.176	-3.76
-2.576	-1.979	-3.44
-2.374	-1.770	-3.12
-2.174	-1.562	-2.80
-1.966	-1.346	-2.47
-1.759	-1.128	-2.15
-1.547	-0.903	-1.83
-1.339	-0.679	-1.50
-1.125	-0.450	-1.18
-0.913	-0.222	-0.84
-0.699	-0.009	-0.51

Table 8: Con't.

FP1 [V]	FP2 [V]	angle [deg]
-0.478	0.237	-0.20
-0.290	0.452	0.11
-0.071	0.683	0.43
0.151	0.904	0.77
0.372	1.124	1.10
0.589	1.339	1.41
0.812	1.550	1.73
1.032	1.756	2.07
1.255	1.961	2.39
1.471	2.158	2.70
1.690	2.353	3.02
1.902	2.542	3.36
2.113	2.728	3.68
2.315	2.906	4.00
2.515	3.083	4.33
2.706	3.255	4.63
2.896	3.422	4.96
3.080	3.587	5.28
3.257	3.745	5.59
3.431	3.902	5.92
3.599	4.051	6.23
3.764	4.201	6.54
3.922	4.345	6.86
4.079	4.487	7.16
4.229	4.622	7.47
4.378	4.757	7.78
4.520	4.887	8.08
4.660	5.014	8.39
4.795	5.137	8.70
4.927	5.257	9.00
5.051	5.372	9.30
5.172	5.486	9.60
5.289	5.595	9.90
5.398	5.698	10.20
5.503	5.800	10.49

F Herschel Pointing Accuracy

RD-22: During all scientific observation modes requiring periods of stable pointing, the pointing requirements with the goals as specified in the Tbl. 9 below will be met with a single calibration once per month (TBC). The line of sight (LoS) of an instrument is defined as the direction on the observed sky of the geometric centre of an FPU entry beam s far field pattern as projected by the telescope. Note that the definition applied to requirements and goals is:

Requirement	performance to be satisfied under all applicable conditions and margins
Goals	performance to be satisfied under restricted, but realistic and specified, conditions and without margins

Terminology:

- Attitude Measurement Error (AME): AME is the instantaneous angular separation between the actual LoS direction and the estimated LoS direction. This is referred to as "a posteriori knowledge".
- Absolute Pointing Error (APE): is the angular separation between the desired LoS direction, and the instantaneous actual LoS direction.
- Relative Pointing Error (RPE): is the angular separation between the instantaneous LoS direction and the short time average LoS direction during some time interval. This is also known as the pointing stability.
- Pointing Drift Error (PDE): is the angular separation between the short time average LoS direction during some time interval and a similar average LoS direction at a later time.
- Absolute Rate Error (ARE): is the difference between the actual and the desired angular rate about the eigen axis of the manoeuvre. This applies only for line scanning.
- Spatial Relative Pointing Error (SRPE): is the angular separation between the average actual LoS direction and a desired LoS direction which is defined relative to an initial reference direction.

Overview of the Herschel Pointing Requirements:

In consecutive pointings within 4 × 4 degrees spherical area, the SRPE of all pointings following the initial pointing, as referred to the average (barycentre) pointing direction of the first pointing will be less than 1arcsec (68% probability level).

The initial reference direction is the average direction of the first pointing. The actual direction of the first pointing will lie within a cone of half angle RPE around this reference direction. The pointing reference axes for all consecutive pointings are specified as angular co-ordinates with respect to the initial reference direction. (SPIRE and HIFI peak up procedure accuracy shall be better than 1 arcsec around the spacecraft Y and Z axes). To meet the line of Sight pointing requirements, the long term error between the LoS reference and the scientific mode attitude sensors will be-calibrated and if necessary, compensated by target attitude generation (bias compensation). All instrument LoS will be calibrated versus ACMS sensors LoS. For that purpose, all instrument shall provide to ground, the information for knowledge of its detector LoS attitude with an accuracy better than 1 arcsec (goal : 0.6 arcsec) in Earth Centered Inertial J2000 frame. Long term and short term parts of that accuracy shall be negligible

Table 9: Herschel Pointing Requirements. Note: w is the scan rate in arcsec/sec. APE scanning mode requirements and goals around LoS are described below in the paragraph on the Herschel slews performances.

ERROR	Line of sight [arcsec]	Around line of sight [arcmin]	Goals for line of sight [arcsec]	Goals around line of sight [arcmin]
APE	< 3.7	3.0	< 1.5	3.0
APE scanning	$< 3.7 + 0.05\cdot w$	n.a.	$< 1.5 + 0.03\cdot w$	n.a.
PDE(24 hours)	< 1.2	3.0	n.a.	n.a.
RPE (1 min) pointing	< 0.3	1.5	< 0.3	1.5
RPE (1 min) scanning	< 1.2	1.5	< 0.8	1.5
AME pointing	< 3.1	3.0	< 1.2	3.0
AME scanning	$< 3.1 + 0.03\cdot w$	3.0	$< 1.2 + 0.02\cdot w$	3.0
AME slew	< 10	3.0	< 5	3.0

(<0.05 arcsec). Attitude information will included be in the TM. The accuracy (eventually after ground processing) will be compliant with the specification Tbl. 9.

The maximum slew rate will be 7°/min (or larger) when the slew angle is large enough to permit full angular velocity. For slews smaller than 16 arcmin (Φ in arcsec), the time to acquire the target will be:

maximum: $10 + \sqrt{(2\Phi)}$ sec
goal: $5 + \sqrt{(\Phi)}$ sec

It will be possible to change via command the slew rate between 0.1 arcmin/s and 1 arcmin/s with a resolution of 0.1 arcmin/s. The Absolute Rate Error about the scan axis will be better than 1% of the demanded rate but not less than 0.1 arcsec/s. It will be possible to complete a slew of at least 90° in 15 min, including settling time. It will be possible to execute each 22 hours, 2 of such slews without the necessity of wheel-momentum off-loading. Attitude constraints apply during slews (see section 5.12.10 of RD-22). In case wheels are autonomously off-loaded, Herschel ACMS shall not violate Science Mode pointing requirements for more than five minutes.