Preparing AOTs for the PACS photometer

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Contents

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[*]Incorporating comments from the PACS Calibration Working Group, S. Madden, and L. Rodriguez, and containing color figures.

Document Change Record			
Date	**Author**	**Version**	**Changes**
16/10/03	MS	1.0	Reflected comments from Oct. ICC#17 meeting
22/04/05	MS	2.0	Major changes reflecting the AOT workshops of January and March 05. This version should be considered a new document
December 1, 2005	MS	2.1	Continued update. Includes changes due to FM detectors. Also tried to answer DAC's questions to our best knowledge.

1 Reference documents

Code	Reference	Title
RD1	SAp-PACS-MS-0247-04	PACS photometer focal plane unit user's manual
RD2	PACS-ME-MM-256	Minutes of the PACS AOT workshop #1 - 17/18 Jan. 05
RD3	PACS-ME-MM-256	Minutes of the PACS AOT workshop #2 - 3/4 Mar. 05
RD4	SCI-PT-RS-05991	Herschel pointing modes
RD5	SCI-PT-19552	Herschel pointing accuracy and calibration procedures

2 Purpose of this document

This document is meant to collect our mutual thoughts about possible Astronomical Observation Templates (AOTs) for the PACS photometer. It is generated inside the AOT Working Group, which is a structure that originates from the ICC, and includes members from the instrument team and from the Calibration Working Group (CalWG). A strong involvement from the CalWG is mandatory since this group will have to come up with a calibration plan that covers all selected AOTs.

At the present stage, this documents details the AOTs that have been selected to be implemented for the photometer. A previous version of the document (1.0) listed possible AOTs with a large number of open points. Thoughts and discussions of that version are not necessarily carried forward here. The interested reader is refered to version 1.0 for a more open view of AOTs.

This document can also serve as collecting two series of precious information:

- Tasks for the simulator: at a number of places we identify questions that can only be answered with simulated data. We thus encourage the simulator Working Group to read this document in detail to understand what is needed.

- Open points: these are questions for which we do not have the answer. In principle, once they are listed they are not repeated even if they in fact apply to all the AOTs.

It should be clear to all readers that open points are what they are, i.e. open, because we do not have the answer to the questions. Not because we have not made the choices yet, but really because we lack the elements that would allow us to make these choices. For quite a number of them, it will be an ICC responsibility to make the choices, not the AOT working group's , and definitely not the authors'.

3   Some terminology

The first version of this document was general (vague?) enough that specific terms were not required then. This is no longer the case. Here is a list of terms that should be understood with a very specific meaning.

- **array:**   the full focal plane, i.e. 32×64 pixels in the blue channel and 16×32 pixels in the red channel, $2' \times 4'$ in both.

- **Cal-U file:**   an uplink calibration file, i.e. a file that will tell the instrument how to convert a "real-world" specification such as use long-blue filter into an internal information such move filter wheel to step N.

- **matrix:**   the individual 16×16 pixel components of the arrays, 8 one the blue side and 2 on the red side.

- **virtual aperture:**   A location in the focal plane that we predifine so that we know that if we ask the telescope to point to a target using a given virtual aperture, the source will fall at this predefined location on the arrays. The first obvious "virtual" aperture is the center of the array but, as explained later on, it is not a very smart choice.

4   A simple description of the PACS bolometers

The PACS photometer focal plane is made up of two detectors, the blue one, for the 60-85 and 85-130 μm filters, consisting of 8 16x18 bolometer matrices[1], and the red one, for the 130-210 μm filter, consisting of 2 16x18 matrices. Contrary to classical bolometer arrays (SCUBA, MAMBO or SPIRE), the bolometer pixels are arranged in a square pattern, with a much higher sky coverage. The sky coverage of a matrix is not complete, because each pixel is enclosed in a square cavity whose walls have a width of ~15% of the pixel width. This implies that for each pixel, including the walls, only 73% of the surface is sensitive. However, the Point Spread Function of the instrument is such that its width corresponds to at least two pixels (see table 1). This ensures that interpolation of the missing flux between pixels can be done safely.

Table 1: PSF size in pixel unit for the three PACS filters

$75\,\mu$m	$110\,\mu$m	$170\,\mu$m
1.8 pix	2.6 pix	2.0 pix

The matrices are also separated from one-another by roughly 1 pixel, which creates the only significant large insensitive area in the focal plane. While the original specification for this gap was exactly 1

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[1]The individual bolometer matrices are indeed 16x18 because we have 2 rows of blind pixels, i.e. pixels that are covered and receive no light. Originally, these pixels were used in read-out scheme. This is no longer the case for the FM, the blind pixels are still there, but they are not used. The matrices are arranged in the focal plane so that the blind pixels are on both long sides of the field of view for the blue detector, and on one long side of the field of view for the red detector.
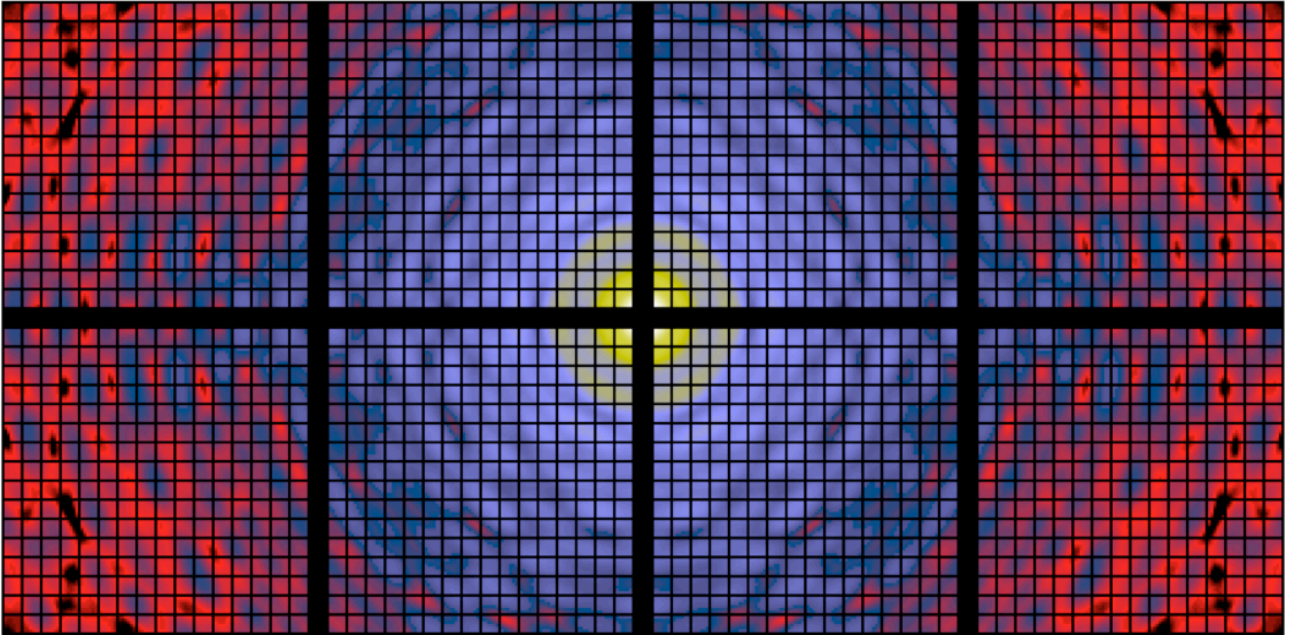
Figure 1: A simulation, by K. Okumura, of a point source observation. This shows the distribution of the flux as a function of position, taking into account the insensitive part of the focal plane. In this example the source is at the geometrical center of the array, which is not a particularly smart choice. This is a logarithmic display of the intensity falling on the detector (dynamic range display is 10^7), no noise or instrument physiscs, apart from its geometric optical ones, is yet included. Note that with the source at the center of the focal plane, only 18.6% of its flux falls on sensitive parts of the detector.

pixel, it was found that for mechanical constraints during the mounting of the matrices, it needs to be increased at a value slightly smaller than 1.5 pixels. Though the situation is not as severe as with classical bolometer arrays, these insensitive zones place some constraints on the pointing strategies used in the AOTs. For instance, we should remember that the pointing center for the photometer should not be the geometrical center of the array. Figure 1 shows why: this point is blind in blue and red. The specification on the relative positionning of the matrices in the focal plane is that they are aligned to better than $1/10^{th}$ of a pixel, or $\pm 40\,\mu$m. We will measure their relative positions at room temperature with an accuracy of $1\,\mu$m. The OGSE also allows measurement of the focal plane geometry at cold temperatures, by scanning point source in the field of view.

The foreseen readout mode for these bolometers is also different from that used commonly. It is called differential double correlated sampling (ddcs) because two internal references are used. First, through the line that was originally used to heat the blind pixels, we now inject a reference voltage at the detection circuit level, V_{ref}^{DC}. Reading this reference goes through exactly the same process as reading any other pixel output. Then, in the readout circuit, there is an internal voltage reference, V_{ref}^{RC}. Switching from the pixel to its reference occurs after the multiplexing (from the controlling electronics point of view). In ddcs, we sequentially read a pixel, $V^p(t_1)$ and the readout circuit reference $V_{ref}^{RC}(t_2)$, while simultaneously doing the same for a detection circuit reference $V^{DC}(t_1)$ and a readout circuit reference $V_{ref}^{RC}(t_2)$ again. The transmitted signal is $(V^p\text{-}V_{ref}^{RC})\text{-}(V_{ref}^{DC}\text{-}V_{ref}^{RC})$. This may look like a complicated way of writing $(V^p\text{-}V_{ref}^{DC})$ but this is not really the case as the two RC reference readouts are made through different parts of the readout circuit.

The DC reference level is typically set so that it cancels the signal from the telescope (we assume that this background is stable on an operational day, but see note 1 below). It is supposed to eliminate drifts that would affect the whole array (e.g. temperature drifts), while the internal reference serves to cancel noise components that could occur in the readout circuit. Low-frequency noise, which will likely affect the detectors, has to be dealt with in the observing strategy.

In order not to be surprised when discovering the first data (simulated or real), remember that each matrix is read by column (in the sense of figure 1). This can create some temporary vertical stripes on the array when the field of view changes rapidly (i.e. the leftmost columns of the matrices are read when still on the first f.o.v while the rightmost part of the matrices are read when we have reached the second f.o.v.). The readout process is simultaneous for all 10 matrices (8 blue and 2 red).

Still on the readout process, remember that once the bolometers are switched on, frames are obtained at a constant frequency (baseline is 40 Hz) until they are switched off. There is no concept of integration time, nor of observation start. The bolometers will never stop producing images of their field of view (hopefully).

Note 1: We presently do not think that the level of the DC reference pixels should be adjusted often. We foresee that the operational day of the photometer begins with a procedure similar to the following: after some health checks[2]: (1) the reference level is varied, while data is recorded, over a range of values that encompasses the current predetermined setting. (2) Once this is done, the reference level is set to a predetermined value for the day. (3) At the end of the day, contact occurs with the ground station and the data is downlinked and analyzed in order to find the actual value that cancelled the telescope background. This becomes the new predetermined setting, to be uplinked at the next "rendez-vous" with the satellite. As this experiment is repeated everyday, trend analysis will tell us whether we can forecast what the reference level should be. Setting that level is as fast as any telecommand to the photometer electronics. The operational scheme of Herschel imposes a minimum delay of two days between the time when we realize something has to be changed, and the time when it is actually modified. This is the reason why at step (2) the predetermined value is re-set.

Note 2: We do not foresee that the temperature of the focal plane arrays will be controlled, although this is in principle feasible by playing on the cryocooler and pre-implemented in the electronics. We think that attempting to control this temperature would result in a supplementary noise component, while in the present situation it just slowly drifts (and the drift is very small for most of the cycle).

Note 3: One should remember a particular feature of these bolometers: they do not integrate the signal, contrary to how photoconductors are operated generally. Their temperature fluctuates according to the luminous power that falls on them, and we read at regular time intervals this temperature. The observing time is a

All this being said, let us detail the different AOTs that have been selected to fly on the PACS photometer.

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[2]Analyzed either by the on-board computer, or on the ground at the next telemetry download. In the procedure outlined here, no real time action is required.

5 Some general notes

5.1 Specifics of space observation

The facts that (1) PACS is equipped with a chopper and (2) we operate in a wavelength range not too distant from that of ground-based submillimeter observatories, lead to some possibly false ideas regarding how we should observe with the PACS photometer.

One should remember that chopping on the ground is done at a relatively high frequency (1 Hz or higher) to cancel high frequency variations in the atmosphere (foreground emission), and that nodding (beam exchange) is performed at a much lower frequency to cancel telescope emission structures in the field of view that differ from one beam to the other.

With Herschel, we can surely expect that our foreground source, the telescope, will exhibit flux variations on time scales that are longer than the typical observation. Our problem with chopping and nodding becomes driven by the low-frequency noise and bandpass of the detector. We should make sure that the signal is modulated (but not necessarily with the chopper, i.e. in a scan or in a raster the signal in "naturally modulated") at a frequency which is higher than that of the LF noise appearance while being smaller than that at which the bandpass of the bolometer cuts the signal, i.e. nominally between 0.1 and 5 Hz.

Thus, although it is technically feasible to chop (and to a lesser extend nod) in all candidate AOTs presented here, we only assume that chopping and nodding are part of the baseline in the point source photometry AOT (because it is a staring one).

5.2 Calibration of the bolometers

PACS is equiped with two internal calibration sources. We write this document in the general assumption that a short cycle of chopped observation on each of the two sources is enough to monitor with a high accuracy the absolute evolution of the gain and offset level of the bolometers (the offset level is irrelevant in chopped observations, but not all observations are chopped).

Whether this is true, or whether it requires an extra step of "calibration" of the calibration sources, is of no concern here. This should be dealt with by the PACS on-board calibration plan.

Thus the basic calibration block of all AOT will consist of a certain number of chopped observations of the two internal calibration sources, with each plateau lasting a given time. The number of chop cycles and the length of the chop plateaus can only be decided after the end of the FM tests.

During operation, there will quite likely be an OBCP, with parameters contained possibly in a Cal-U file, to perform the calibration observation. This Cal-U file is probably a good place to hold the value of the maximum time that may elapse between two calibrations.

5.3 Defining the observing time

As noted earlier, the bolometers are operated in such a way that they do not integrate the signal. They more or less instantly adjust to it, and we constantly read the adjusted value. This prevents the definition of a meaningful integration time.

Yet time is an important aspect of astronomical observation and we should have a definition for

something like the observation time. One possibility is this on-source time. This is indeed a more "user-oriented" time as it does not include the instrument overheads, which are currently a dark mystery, and furthermore it is a time that can be used as input to a sensitivity estimator. However it is not free of ambiguities in its definition. For instance in a chopped and nodded AOT, this time is typically half the time spent on the sky acquiring science data. But in a mapping AOT this is certainly not the case. Therefore we propose to use here a new definition that, for lack of a better word, we will call the "science" time, T_{sci}, and that is the time, in an observation, which is spent obtaining science data. Thus calibration time is not part of T_{sci}, slew times are not part of T_{sci}, instrument overheads are not part of T_{sci}, telescope overheads are not part of T_{sci}, but the time spent on the OFF field in a chopped AOT is part of T_{sci}, all the time spent on each raster position of a raster map is part of T_{sci}, and all the time spent on the legs of a scan map is part of T_{sci}. It seems that this time is one that can rather straightforwardly and homogenously be defined for any observation, and we use it throughout this document[3].

6 A brief description of the candidate AOTs

The photometer will propose three generic AOTs[4]:

- **Point Source Photometry:** This is reserved for the observer who will want to target a source that is completely isolated and point-like or smaller than one blue matrix. A typical use of this AOT would be for photometric calibration (although we will also observe photometric calibration sources with the other AOTs). it uses chopping and nodding, both with amplitude of 1 blue matrix, and dithering, with a 1 pixel amplitude, keeping the source on the array at all times.

- **Small Source Photometry:** Here the term small source refers to sources that are smaller than the array size, yet larger than a single matrix. To be orientation independant, this means sources that fit in $2' \times 2'$. This AOT also uses chopping and nodding, but this time the source cannot be kept on the array at all times.

- **Extended Source Mapping:** This time the source is significantly larger than the array, or the objective is to cover a large contiguous area of the sky. We identified three possible ways of performing this kind of observation: through scanning without chopping, raster with chopping, and freeze-frame scanning.

The name of these AOT is possibly not the best as they could lead the observer to believe that they are restricted to a type of source. Again, this is an implementation problem for HSPOT, of no concern here.

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[3]We did not invent this time here, it is widely used for instance in the ESO templates for a number of its instruments.

[4]We call here an AOT an observing mode that has sufficient particularities to be identified as such. How HSPOT decides to implement/hide this from the user is of no concern to us here as this is strictly an internal PACS document.

7 Point source photometry

7.1 detailed Description

This AOT shall be used only for sources that are significantly smaller than a single matrix, i.e. point sources mostly. We will use the chopper to alternate the source between the left and right part of the array (i.e. the ON and OFF positions), and a command to the satellite (nodding) to alternate it between the top and bottom part of the array (i.e. the A and B positions, see Figure 2). In the baseline AOT, the chopping and nodding axes are orthogonal. On the blue side this means that we will effectively use only 4 out of the 8 matrices. It is currently preferred to use the 4 central matrices, in a compact, centered configuration, but it could be changed to either any adjacent group of 4 matrices if the chop throw is set to twice the matrix size, or two sets of two matrices separated by 1 matrix for a throw of twice the matrix size, or separated by 2 for a throw of three times the matrix size. This leaves an adjustment margin to account for the cosmetic quality of the array. Consequences on the red are that the whole observation could be done using only one of the matrices. This AOT is described assuming we use the central part of the array.

The chopper is also used to perform a small dithering, through a pre-determined sequence along the y-axis. This dithering pattern will have to be established during FM tests.

This 4-position AOT is preferred to a 3-position AOT (i.e. one where the nodding and chopping axes are parallel) as it seems the 4-position configuration can have better performance in terms of flat-fielding errors (mostly because we average them over more matrices. One should remember that the nodding motion is used to allow the subtraction of telescope structures that could be imprinted on the field of view. It is thus important that it is performed with the telescope, and not with the chopper, even in the 3-position AOT. In the same line of thought, one has to remember that, if the detector is very stable, and telescope emission remarkably flat, we may dispense with chopping and nodding altogether, but that if we use the internal chopper for any purpose (i.e. modulation or foreground subtraction), we have to nod as well to compensate for the differences in optical path. Thus the baseline is chopping with the internal chopper, and nodding with the telescope.

We have to explore, with the simulator, whether it improves the data quality or not to have throws that are not an integer number of pixels. Given that there are insensitive areas between the pixels, it could make sense indeed to "cover" this area with adequate chop and not throws, i.e. amplitude that do not exactly place one pixel on top on another.

7.2 User input

Table 2 contains the list of information that is requested from the user. It will be used to generate the command sequence but also as input to the time estimator. The time estimator does not need all the information presented here to run. Regarding the simulator, it is in principle able to work with two out of the three data points (S/N, Flux, T_{sci}) to produce the third one. However in the framework of the AOT description, T_{sci} is the only parameter that allows the creation of a schedulable observation (i.e. one that does not evolve too much when the uplink calibration files evolve).

Nod 1 Chop A Nod 1 Chop B

Nod 2 Chop A Nod 2 Chop B

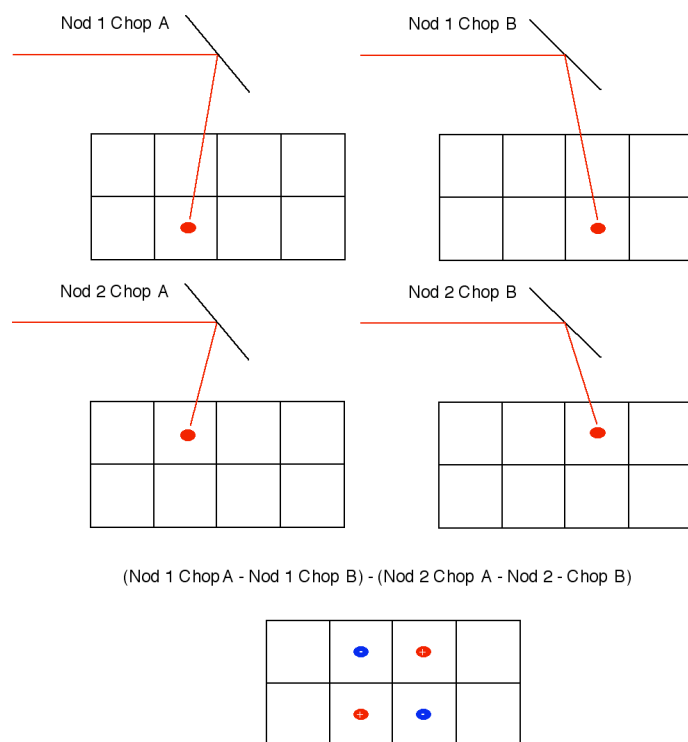(Nod 1 Chop A - Nod 1 Chop B) - (Nod 2 Chop A - Nod 2 - Chop B)

Figure 2: a small sketch showing the source positions as a function of the nod and chopper positions. Optical pathes are not drawn accurately, the y-axis is to the left, the z-axis to the top. Chop positions are defined by the internal chopper, while nod positions are defined by the satellite pointing. Chopper positions A and B are subtracted from one another to suppress the background and deal with possible low-frequency drifts, differences obtained in nod position 1 and 2 are subtracted from one another to remove remaining telescope contributions. In the resulting image, the source in positive when red, and negative when blue. These four images can be folded on one another to make a single image. Dithering at each chopper position, performed with the internal chopper, is not represented. This figure deals only with the blue array but the red side figure is simple to extrapolate. It shows the case of the compact, centered chop-nod configuration. As mentionned in the text, other configurations can be defined to use another set of matrices.

PACS

Herschel

PACS photometer AOTs

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Table 2: User input parameters for the point source AOT.

Parameter name	Signification and Comments
α, δ	Coordinates of the source, the equinox may be a parameter
Filter	This is which blue filter to use. At the time being it is decided that an observation that requests all three photometer bands needs two AOTs as we do not want to interleave chopper and filter wheel motions.
Dithering	[Y/N] parameter. The dithering pattern will be fixed with an amplitude in the range of 1 pixel.
Chopper avoidance angle	An angle, defined following the PA convention (positive east of North). As the chopper cannot rotate, this effectively defines an avoidance angle for the satellite orientation. Hence it is a scheduling constraint.
T_{sci}	Science time. See section 5.3 for the definition.
Gain	This the electronic gain. It is not advised to change it except for the very bright sources (planets and asteroids).
Flux	This can be either a value for each bands (recommanded) or a single value. This parameter is useful only for the time estimator.

7.3   Fixed input - Cal-U files

Here we give the remaining parameters of the AOT, which are required to make it work but not accessible to the user. Table 3 contains parameter values, while Table 4 contains the list of Cal-U files that are needed to implement this AOT.

Table 3: Fixed input parameters for the point source AOT.

Parameter name	Signification and Comments
Chop throw(s)	This is the amplitude of the chopper motion but, to cover the possibility of adding dithering, it is more a list of chopper positions, making a cycle that can be repeated a number of times.
Chop frequency	The frequency at which we move the chopper. Given that the detector has a finite response time, it is safer not to let the observer play with this.
Nod throw	This is the amplitude of the telescope motion. Here there is only one possibility: almost the angular size of one matrix in the z-direction.
Nod frequency	The frequency at which we ask the telescope to move back and forth between the two nod position. It should be smaller than the chop frequency.

7.4   Virtual aperture

The baseline is to implement it with the *composite nodding* pointing mode of Herschel. In that case, the virtual aperture should be located at the center of the array in the y-direction, and 1/2 a matrix below that center in the z-direction. Two symetrical positions of the chopper will define the ON and OFF beams.

Table 4: Cal-U files for the point source AOT.

| **Parameter name**	**Signification and Comments**
Chopper position conversion	A file that contains the conversion from chopper steps into deflection angles. It is the same file that is listed in Table 5
Chopper position on ICS	For calibration purposes we need a file that contains the position of the chopper that give the "best" illumination from the internal calibration sources.
Filter	A file containing the filter wheel positions corresponding to each of the two blue filters.
Saturation/gain change limits	This information is needed to warn the observer of potential problems with the set-up. What do we do when these limits are reached?
Sensitivity	Needed for the time estimator.
Spatial configuration	To command the nod throw, we need information on the focal plane geometry and pixel scale. We also need this information for a correct time estimation. This is the same file as in Table 5.
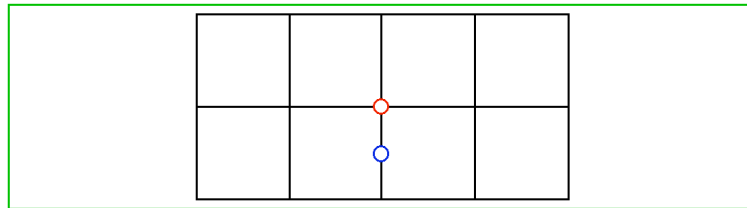
Figure 3: The virtual aperture for the point source AOT. The green box is an approximate drawing of the complete field of view of the photometer on the sky (calibration sources are not drawn). The array position is that obtained for the nominal chopper position (i.e. step = 0), not the ON or OFF position of the AOT.

This apertures is shown on Figure 3 for clarity.

7.5   Pointing sequence

The pointing sequence for this AOT is rather simple to start with because we only need two pointings: one for each nod position. It gets more complex when calibration is considered as we probably need to observe the ICS during the observation itself. However RD4 proposes one pointing mode which is exactly what we need: the *composite nodding* mode. This mode allows us up to 1200 switches between two positions defined necessarily along the satellite's axis. RD4 is a little bit ambiguous and it is hard to see whether it is only the y-axis, which is useless for us, or the z-axis, which is what we want.

It is of paramount importance that all data from the photometer from the initial slew to the end of the observation is recorded and downlinked. These data may end up playing a crucial role in the data reduction process.

7.6   Internal calibration

Internal calibration will be performed according to section 5.2. This will be performed at the start and end of the AOT, and as during the AOTs. Typically it should be placed after the completion of

a nod cycle (a complete ABBA sequence).

We are going to take advantage of the *hold* mechanism that allow us to define periods in the AOT where the satellite simply waits for the instrument to complete a procedure. A first calibration can probably be performed during the slew to the source, or with the *inithold* parameter, a last one with the *finalhold* parameter, and for calibrations that have to be done at regular intervals during the observations, with the *thold* parameter (prefered to the *loadslew* parameter because of its placement in the pointing sequence). Finalization of the calibration strategy will be done after the FM tests.

7.7 Data reduction

This section is a transcription of the discussions that have taken place during the second AOT meeting (RD3). I have changed a few points following my personal inclination.

An important point to remember is that the starting point of photometer data reduction consists in images that are sampling the focal plane at a nominal rate of 10 Hz. These images are the sum of nominally 4 readouts obtained at a 40 Hz frequency. In the IA terminology, we thus start with frames.

In the telemetry, the frames are in digital units. With the gain they can be converted to V, and with the sensitivity parameter, they can be converted to Jy. The ideal location of these conversions can be debated. Here we first convert to V (or possibly μV to avoid carrying factors of 10^{-6} everywhere).

Then we identify glitches and possibly saturation events in the data cube, and mask those data. At a later stage we may find algorithms to really correct the data for the glitch or saturation effect.

Then we label the frames. These labels should be (at this stage we can probably ignore the dithering pattern, see also open points):

> Cal ICS1
> Cal ICS2
> Chop ON Nod A
> Chop OFF Nod A
> Chop ON Nod B
> Chop OFF Nod B
> Moving chopper
> Slew

Note that the above sequence is not a time sequence, it is just a list. Some frames, in particular to and from the off position (labelled moving chopper), will contain useless data for science. They should however not be discared because they may help us correct some artefact. In general, no data should ever be discarded from the datacube. It should be flagged so that further processing is able to ignore it if need be.

The ICS1 and ICS2 frames are subtracted from one another to give an indication of the flux calibration. It remains to be seen whether we should use these measurement as the flux calibration or as an indication of the stability of the flux calibration, with respect to measurements done more carefully with dedicated AOTs.

If the internal calibrations show that the responsivity is changing, these variations should be corrected here.

In the science data (the 4 labels with Chop), we now need to make the differences between the ON and OFF positions and then between the A and B positions. This will give us an image that looks a bit like the end image of Figure 2. There will be an associated weight image that will tell us how many frames are actually used for each pixel, as this is useful to compute the noise and will vary because of glitches. When we make these differences, we must be carefull of how dithering was implemented: we cannot sum together images where the source is not at the same pixel location in one of the beams. If dithering has been used and optical distorsion is strong then optical distorsion correction has to be applied first, before the dithering is taken into account.

After this stage, if it is known, the data should be flat-fielded.

Folding of the 4 images on one another is the last operation to perform. This folding should take into account distortion corrections, though this is not completely straightforward.

After that, one converts from μV to Jy, computes the noise map, all this taking the weights correctly into account, and the astrometric information is associated to the image, possibly in through a projection on the sky.

This data reduction process leads to the identification of a number of calibration files which are listed in table 5.

Table 5: Calibration files needed to reduce the point source AOT.

Name	**Signification and Comments**
Gain	We just need to know how many μV per digital units we have in the different gain modes
Glitch and saturation threshold	This more generally should contain the value for the adjustable parameters that future glitch and saturation detection algorithms will use.
Flat-field	Either a series of images, or algorithms to extract it form the data.
Sensitivity	To convert from μV to Jy, for all configurations of the photometer. This could also take the form of a recipe to extract it from the calibration observations performed in the AOT.
Chopper position conversion	The chopping and dithering patterns are described in terms of chopper positions. We need a file that tell us where the virtual aperture falls for each of these positions.
Spatial configuration	To create a correct astrometry, and reproject on the sky we need information on the focal plane geometry, such as distortion, location of gaps in the focal plane, pixel scale.

7.8 Open points

- The dithering pattern, made with the chopper in the y-direction, needs to be more clearly defined as its implementation has consequences on the data reduction process.

- Since we are using quite large filters, we need a clear definition of our photometric system when we do the flux calibration.

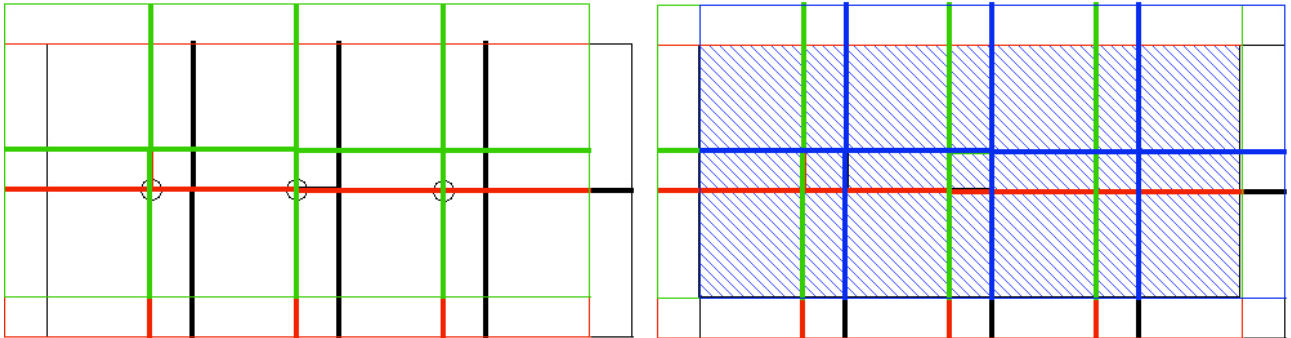- Some description of the glitches, their duration, would be interesting.

Figure 4: What we draw is the footprint of the detector on the sky with, in thin lines, the surface of the detector and, in thick lines, the gaps between the matrices. The pointing sequence is color coded and goes black, red, green, blue. The figure on the left shows the resulting footprint after one y-axis and one z-axis motion. By the y-axis motion alone, the horizontal gap betwen the 4 top and bottom matrices is still completely blind. The z-axis motion covers almost all this area except the three encircled pixels. A second y-axis motion, in the opposite direction to maximize the overlap area, leads to complete coverage. The completely covered area at the end of the observation is indicated as a hatched zone. This figure is really best viewed in colors.

- The frequency at which calibrations have to be performed is not decided yet.

- How do we take into account optical distortion effects in a chopped and nodded observation such as this? Chopping and nodding both change the optical path and thus quite likely the distortion pattern as well. Therefore it is not clear at which point we correct for it, before or after chopping and nodding subtraction? This is a task for the simulator.

8 Small source photometry

8.1 Detailed description

The term "small source" is used here to refer to sources that are slightly smaller than the array (i.e. $2' \times 4'$ or, to avoid problems with the array orientation on the sky, $2' \times 2'$), but more extended than a single matrix.

In that case, a very small raster is probably the best way to observe it. With the pattern of gaps we have, and considering only the large gaps between matrices, we need 3 to 4 different pointings to recover the signal lost between arrays and pixels, depending on whether or not we use diagonal motions. There does not seem to be a pointing mode in RD4 that would allow a simple scheduling of diagonal motions with respect to the array. Therefore the baseline is to use a 2×2 raster. This also offers the advantage of a larger fully-covered area. The parameters of this raster (i.e. the displacement in both directions) are probably better fixed than left to the observer's choice. Their values should be decided after FM tests and placed in a Cal-U file.

Although the y-axis motions can be performed with the chopper, and would thus be faster and more accurate, it is probably unwise to do so as any chopper motion changes the optical path and so possibly affects the structures in the background that would become hard to remove. It is probably better to leave the chopper alone with respect to the pointing.

The question is still open regarding whether we shall use the chopper in this AOT. Given that the raster is very compact, it is physically possible to make, with the chopper, a complete OFF raster associated to the main observation (i.e. we perform full-amplitude chopper cycles at each raster position). However as we have argued before, chopping changes the optical path and if the telescope structures are sufficiently bright, they will create artefacts in the ON-OFF images that cannot be removed. The only way to remove them would be to nod, as we perform the raster. RD4 contains pointing modes that could provide us with this facility (*nodding of raster* or *nodding in raster*) however these modes are not implemented yet. Therefore as a baseline, the chopper is not used in this AOT, but we will keep the pointing sequence open, with the possibility to implement chopping and nodding at a later time. As a consequence, the rest of this section will contain information that relate to that optional implementation.

We should avoid using steps that are an integer number of pixels as this will insure that small gaps between pixels are never covered. Given that 2 blue pixels are 1 red pixel, a step of 8/3 blue pixels (~ 8") is a good value as it moves the objects by at least one pixel on both arrays and still does not decrease too much the total field of view. These values should be revised once we have an accurate description of the focal plane geometry, and in particular when we know the exact value of the gap between the matrices. These numbers assume it amounts to exactly one pixel.

There are "morphological" similarities between this AOT and the point source AOT, but one should note a very important difference: the 4 positions are achieved with the telescope, whereas in the point source AOT we used the telescope only for the z-axis motions. Also we do not foresee to propose dithering as an option here. In a sense dithering is achieved by the 4 positions of the small raster.

As the raster is designed to fully sample the field of view, we impose that it is done along the satellite's axis, and we also impose the raster steps. But since the field is rectangular, some observers may want to constrain the orientation of the satellite on the sky (e.g. is their object is elongated).

8.2   User input

This input is similar, if not identical, to that of the Point Source AOT. Nevertheless we repeat in Table 6 the complete set of information we expect from the user.

8.3   Fixed input - Cal-U files

Given that (1) chopping is no longer part of the baseline of this AOT, and (2) the raster parameters are placed in a Cal-U file to allow an easy modification, there are no fixed inputs in this AOT, only Cal-U files listed in Table 7. This may actually be the preferred situation. If we implement chopping and nodding, we will probably have to include fixed inputs describing the chopping and nodding configuration.

8.4   Virtual aperture

To understand the location of the virtual aperture, one must remember that the general definition is that it is the location in the full photometer field of view where we want the telescope to place the point in the sky that has the "source" coordinates, as entered in the AOT, when the chopper is at its

Table 6: User input parameters for the small source AOT.

| Parameter name	Signification and Comments
α,δ	Coordinates of the source, the equinox may be a parameter
Filter	This is which blue filter to use. At the time being it is decided that an observation that requests all three photometer bands needs two AOTs as we do not want to interleave chopper and filter wheel motions.
Raster orientation	This defines the position angle of the major axis of the array (and raster). This will limit the schedulability of the observation. It should in fact be an interval of angles to allow the observation to be scheduled.
T_{sci}	Science time. See the definition of this in section 5.3. The time per raster position is $1/4^{th}$ of it.
Gain	This the electronic gain. It is not advised to change it except for the very bright sources (planets and asteroids).
Flux	This can be either a value for each bands (recommended) or a single value. This parameter is useful only for the time estimator.
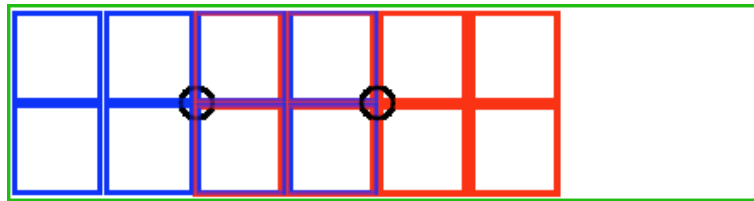
Figure 5: The virtual aperture for the small source AOT. The green box approximately delineates the photometer field of view (calibration sources are not shown). The red array is the location of the photometer array when the chopper is in its nominal position (i.e. 0). The black circle is the virtual aperture. In case we implement chopping, the blue array is the location of the photometer when the chopper is in the ON position, and the grey circle is the new virtual aperture.

nominal central position.

But here the "source" coordinates are those of the center of the object the observer wants to image, while the coordinates that the telescope will slew to (i.e. the pointing request) are those of the first point in the raster.

Therefore I now take on the definition that the virtual aperture is that location in the photometer field of view where we want the telescope to place the point in the sky it is slewing to in response to the pointing request.

In a raster which is implemented without chopping, that defines the virtual aperture as the exact center of the field of view.

In case we implement the chopping and nodding option, the virtual aperture has to be displaced: the available field of view is twice the array size, and we want to chop completely off array. This means our ON field is completely on one side of the array, and our OFF field completely on the other side. This moves the virtual aperture the equivalent of two matrices along the long axis of the photometer.

These two virtual apertures are shown on figure 5.

Table 7: Cal-U files for the small source AOT.

Parameter name	Signification and Comments
Raster parameters	These are the steps in the x and z direction.
$T_{staring}^{max}$	The maximum time that should be spent staring at the same position. This helps decide whether the raster needs to be repeated rather than extended.
Chopper position on ICS	For calibration purposes we need a file that contains the position of the chopper that give the "best" illumination from the internal calibration sources.
Filter	A file containing the filter wheel positions corresponding to each of the two blue filters.
Saturation/gain change limits	This information is needed to warn the observer of potential problems with the set-up. What do we do when these limits are reached?
Sensitivity	Needed for the time estimator.
Spatial configuration	To define correctly the raster steps, we need information on the focal plane geometry and pixel scale. We also need this information for a correct time estimation. This is the same file as in Table 5.

8.5 Pointing sequence

RD4 proposes a rather ideal pointing mode for this AOT: the *repeated raster with hold* mode. In this mode a raster pattern can be performed, interleaved with hold times at regular intervals, and can even be repeated. This mode has both *inithold* and *finalhold* parameters that allow for the initial and final calibration to be performed. If turns out that it is better to do short raster sequences and repeat them rather than long stares at each position, we will use the repeat mechanism of the AOT. This may actually be a very good way of ensuring a proper modulation of the signal.

In case we implement the chopping and nodding in this AOT, one must make sure to have a complete series of ON-OFF cycles at each raster position, and for each nod-position. Currently the proposed implementation of nodding in/of raster ensures that we have complete nod-cycles at each raster position. However synchronizing the chopper cycles with the raster motion may not be completely straightforward. We also have to check that the *nodding in/of raster* pointing mode lets us build the equivalent of the 3-points chop/nod or parallel chop/nod observation.

Since we are using the raster mode, we become sensitive to the so called SRPE error that can introduce large astrometric errors (see RD5). However in a 2×2 raster, the effect should be minimal (see discussions in the Herschel Science Team meeting #21). Furthermore we are currently instructed to ignore that problem.

8.6 Internal calibration

Internal calibration is described in section 5.2. There will be one such calibration at the beginning of the observation (e.g. during the slew). There should be at least another calibration at the end of the AOT to detect any response drift. The *hold* parameter of the pointing mode can be used to interleave calibrations are regular intervals in the observation. The actual calibration scheme and frequency will be finalized after FM tests.

8.7   Data reduction

This has not yet been completely elaborated during the second AOT meeting (RD3) but it shares a large number of similarities with the process applied to point sources. This section does not really pretend to make sense and is unlikely to represent the smart way of reducing the data...

The first step is to convert all the frames to V and identify and flag glitches and possible saturation effects.

Then all frames are given a label that corresponds to the pointing status. Here we have more labels but they can be derived from those of the point source AOT by replacing the chop/nod parts by [1,1], [1,2], [2,2], [2,1] (2×2 rasters are perfomed in a "circular" motion, see RD4). Here again, we should only attribute flags, and not get rid of data, hence the slew label will probably be also used for motions from one raster point to the next (as well as to the nod positions if we use them).

Internal calibration measurements can be processed to provide the current responsivity, and possibly the associated drift. This information will be used later in the processing chain. Since in general this is not a chopped AOT, we use the calibration measurement to follow the possible offset (additive) drift in order to remove it from the data. If the responsivity was found to vary significantly during the observation, this drift should be corrected there as well. Note that if rasters are repeated, we can probably extract the drift information from the "science" data themselves.

If chopping and nodding have been implemented, this effectively reduces the field of view (i.e. the region of the array where we know that sources in the ON-field do not contaminate the OFF-field), and we may want to compute, from the chopper and raster parameters, what this field is and mask out the rest of the array to avoid create artifacts in the final image. For each raster cycle, at each raster position, we proceed as in the point source AOT to "collapse" the ON, OFF, Nod-A and Nod-B frames. If optical distortion is known it has to be corrected before that collapse as it is likely different in the ON and OFF positions.

If we are not chopping and nodding, we simply have to average together the sets of frame obtained at each raster position in each raster cycle, and correct them for optical distortion.

This leaves us with a set of 4 average images per raster cycle. Corresponding noise and weight images are created (wheight images simply show how many readouts we used for each pixel of the array).

If a flat-field is available, it should be applied here. If methods to derive the flat-field from the observation are developed, they are applied before we make the chopping and nodding correction (after these corrections the background becomes null and thus nothing is going to tell us what the flat-field was at these locations).

Using the astrometrical information, or reconstructing it from the object if it is sufficiently bright and structured, we reproject the sky, the noise, and the weight images on a regular astronomical grid. It is also the place where the final conversion from μV to Jy.

These data reduction steps lead to essentially the same set of calibration files as for the point source AOT. For clarity they are repeated in Table 8.

Table 8: Calibration files needed to reduce the small source AOT.

Name	Signification and Comments
Gain	We just need to know how many μV per digital units we have in the different gain modes
Glitch and saturation threshold	This more generally should contain the value for the adjustable parameters that future glitch and saturation detection algorithms will use.
Flat-field	Either a series of images, or algorithms to extract it form the data.
Sensitivity	To convert from μV to Jy, for all configurations of the photometer. This could also take the form of a recipe to extract it from the calibration observations performed in the AOT.
Chopper position conversion	The chopping and dithering patterns are described in terms of chopper positions. We need a file that tell us where the virtual aperture falls for each of these positions.
Spatial configuration	To create a correct astrometry, and reproject on the sky we need information on the focal plane geometry, such as distortion, location of gaps in the focal plane, pixel scale.

8.8 Open points

- Do we chop and nod? One does not really go without the other unless we use the telescope to chop. Chopping and nodding may end up being feasible if the *nodding in/of raster* pointing modes described in RD4 are implemented. The necessity to chop and nod will have to be settled from simulations.

- Can we synchronize the chopper and the raster in the sense that at each raster point we are sure to have completed the same number of chopping cycles and that we always start the observation of a raster point with the same chopper position?

- Do we repeat the raster pattern or do we do it only once, and if we repeat it, do we fix the maximum time a single raster can last? This should be considered in connection with the maximum time we allow to elapse between two internal calibrations, and whether we put constraints on this time, or we just advise the observer.

- Do we really allow the user to constrain the raster orientation? This could make sense given the rectangular shape of the effective field of view.

9 Extended source mapping

9.1 Detailed description

This will quite likely be the most widely used photometer observing mode: Herschel was built to make large scales surveys and such observations are not made by pasting together postage-stamp observations such as the ones described above. We currently have identified three possible ways of doing these large maps:

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- **Raster:** the satellite goes through a rectangular grid of points, and stays for a user-specified time at each raster point. There is a dedicated Herschel pointing mode for rasters. They can be combined with chopping, though this will make data reduction complex as the OFF chopper position will now always be in the map. Nodding can also implemented with the pointing mode but will again be done inside the map, which may complicate data reduction. Therefore we will recommend not to chop and nod in raster mode. Rasters can be performed with any orientation with respect to the satellite or the celestial reference frame.

- **Scanning:** in scanning, the satellite slews continuously along parallel lines at a user-specified speed (between 0.1"/s and 1'/s). There is a dedicated Herschel pointing mode for scanning. Although we are in principle free to chop while the satellite is scanning, this may render the map-making process extremely complex, and we again recommend to keep the chopper still. Worth mentionning is the fact that the area seen by the camera will be larger than the one mapped, due to the acceleration and deceleration of the satellite between each scan leg. This could cause problems if the map is made next to a very bright source. It also introduces overheads between each scan leg. Scan legs can have any orientation in the satellite or celestial reference frame. It is not clear yet whether we will advise for or against certain orientations (as in the SPIRE scanning mode). It is however foreseen that scanning along the camera axes generally leads to stripes in the maps corresponding to the blind area between the matrices if the spacing between the legs is larger than one matrix. Note that scanning the sky in a single direction is not enough to guarantee that all drift artefacts can be removed. The only way to do that is to scan the same portion of the sky in a different direction. No pointing mode is available to perform two scans in different directions.

- **freeze-frame scanning:** In this mode we use the scanning pointing mode of Herschel, but we use a saw-tooth chopper motion pattern to freeze the image on the array for a pre-defined period of time (this is fixed by the scanning speed and the chopper pattern). There have been extensive discussions of this mode, which is a relatively new mode for PACS, led by S. Pezzuto. The documents are unfortunately not stored anywhere. Since we are using the chopper to freeze the image on the array, this means that cannot chop and that the scan direction is quite likely restricted to be the y-axis of the satellite. A small angle can be introduced with respect to this direction to avoid striping the map. The larger this angle, the poorer the image freezing will be. It is likely that we do not need to synchronize the chopper with the scan. This mode is effectively a fast raster.

It is not yet clear whether we will offer all these three modes, since a constant thought should be to limit the number of observing modes available. We plan to use the simulator to decide what to do with these three modes. The likely outcome of this exercise is that we will put forward recommendation as to when one should be chosen. Currently we think that small areas are probably best done with rasters (because we do not have the acceleration/deceleration overhead), and that freeze-frame scanning offers the highest surface/time ratio, though at a sensitivity cost which is not seen as a problem by observers interested by extended bright sources (e.g. molecular clouds). We need to have numbers to draw the lines between these modes.

Table 9: User input parameters for the mapping AOT.

Parameter name	**Mode**	**Signification and Comments**
α, δ		Coordinates of the center of the map, the equinox may be a parameter
Orientation		An angle and a reference frame (satellite or celestial) that describe the orientation of the map axis.
Filter		The blue filter to use for this observation.
M, N, ΔM, ΔN	R	The geometrical parameters of the raster (number of points and legs, separation between points and legs).
N, L, ΔN	SF	The number of legs, their length and their separation in a scan map.
T_{sci}	R	Science time, with the definition of Section 5.3.
v_{scan}	SF	The scan speed.
Gain		This the electronic gain. It is not advised to change it except for the very bright sources (planets and asteroids).
Flux		This can be either a value for each bands (recommended) or a single value. This parameter is useful only for the time estimator.

Note for HSPOT: These mapping modes are by far the most complex modes of the photometer. It is mandatory, in order to avoid bona fide costly mistakes from the observers that HSPOT is able to show on the sky, with a resolution of the photometer matrices, the aspect of the map that is currently programmed. HSPOT should also warn when the scan or raster parameters lead to a significant undersampling of the field (i.e. when they lead to holes in the map).

9.2   User input

Rather than dividing these section in three, one for each of the mapping mode, which would lead to many repetitions, I add a column to the tables that contains a code that indicates, when necessary, to which mapping mode the parameter refers. The codes are R for raster map, S for scanning maps, and F for freeze-frame scanning maps. No code means all modes. The parameters we expect from the user are listed in Table 9.

Some comments to this table may be in order:

- The orientation is not a user input that has different consequences depending on the actual mode. For a raster or a normal scan map, specifying the orientation does not restrict the schedulability, but results in a possible orientation mis-match between the array and the raster axis. In the freeze-frame scanning mode as we will probably define "optimal" angles in the satellite reference, the only orientation reference frame that matters is the celestial one, but that strongly restricts the possibility to schedule the observation. We may remove the possibility of selecting the orientation for normal and freeze-frame scan maps, as these modes are targeted at large fields that can be "squared".

- The science time is not the primary parameter when we scan (either normally or with freeze-frame chopping). The observation driving parameter is the scan speed which defines the achieved sensitivity, and combined with the map parameters, gives the total observing time. In freeze-frame, a scan speed is associated with a chopper "waveform" that is specifically made to stabilize

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Table 10: Fixed input parameters for the mapping AOT.

Parameter name	Mode	Signification and Comments
Chopper pattern(s)	F	This is a description of the chopper motion cycles that we allow to perform freeze-frame.
Allowed scanning angle(s)	SF	There will be optimal or better scanning angles (in term of spatial sampling and sensitivity). For freeze-frame mapping this list could have only one element.
Allowed scanning speed(s)	SF	At least in freeze-frame, and possibly also in normal scanning mode, we will want to restrict the available speeds.

the image at that speed. Obviously we will restrict the number of scan speed choices in both scan modes.

- In the "normal" scanning mode, we may want to limit the available scan speeds in order that if we find that calibration and data reduction processes are too dependent on the actual value of the scan speed, we do not run into a calibration problem. It may also be scientifically irrelevant to have more than two choices, slow or fast. Typically we will start significantly degrading the PSF for speeds of 30"/s and above.

- During our January meeting we listed a chopper avoidance angle for the raster mapping. It does not make sense. First is may be incompatible with the raster orientation specification. Then given our small chopping amplitude, we alway chop inside the map, and it is impossible to avoid a zone in the map (unless we do extremely rectangular rasters which would then preferentially be performed with a scan map). Finally, the baseline is now not to chop in a raster mode so this whole point becomes history.

- Still during that meeting we listed a repetition flag for all these mapping AOTs. This in principle indicates how many times the user wants, or the instrument specialists suggest, to repeat the map. It is my opinion that this should rather be treated as an open point for the moment. Repeating a raster could make sense but repeating a scan does not since the pointing mechanism to repeat an observation performs exactly the same sequence. As said before, in a scan we want a different orientation.

9.3 Fixed input - Cal-U files

Similarly, we gather in Table 10 all the fixed inputs that are required to execute the extended source mapping AOT, with the codes R for raster, S for scan map and F for freeze-frame scanning.

Similarly to the small-source AOT, there are no fixed inputs for the raster mode.

For the freeze-frame scanning mode the scan speed and the chopper pattern are linked in the sense that a given scan speed determines the waveform of the chopper motion needed to stabilize the image, and also determines the staring time on that sky position. We will determine which values of the scan speed we allow and compute the associated waveform.

Cal-U files needed to execute the mapping AOT are gathered in Table 11, with similar codes.

Table 11: Cal-U files for the mapping AOT.

Parameter name	Mode	Signification and Comments
$T_{staring}^{max}$	R	The maximum time that should be spent staring at the same position. This helps decide whether the raster needs to be repeated rather than extended.
Chopper position conversion	F	A file that contains the conversion from chopper steps into deflection angles. It is the same file that is listed in Table 5
Chopper position on ICS		For calibration purposes we need a file that contains the position of the chopper that give the "best" illumination from the internal calibration sources.
Filter		A file containing the filter wheel positions corresponding to each of the two blue filters.
Saturation/gain change limits		This information is needed to warn the observer of potential problems with the set-up. What do we do when these limits are reached?
Sensitivity		Needed for the time estimator.
Spatial configuration		To define correctly the raster steps, we need information on the focal plane geometry and pixel scale. We also need this information for a correct sensitivity/time estimation in all the mapping modes. This is the same file as in Table 5.

9.4 Virtual aperture

We use here the same "definition" of the virtual aperture as in Section 8.4, i.e. the location in the field of view where we want the telescope to place the point in the sky it is slewing to. In the case of large mapping AOT, it does not really make sense to define it elsewhere than at the center of the field of view.

When chopping is combined with the raster, then we should apply a reasoning similar to that used for small sources: the virtual aperture is offset from the center of the photometer field of view by half of the chop throw. This ensures again that array is centered on the first point of the raster. Having said that, one immediately realizes that this defines as many virtual apertures as we allow of chop throws. It is unlikely that we will be allowed to do this, assuming we would really want to do it. One could however remark that for very large rasters, this will make little difference since the actual location of the virtual aperture between the center of the array or $3/4^{th}$ of it which is its maximum deviation, would only result in a shift of at maximum $2'$ of the whole map. Yet these very large rasters will probably be done with scanning...

9.5 Pointing sequence

Raster maps will be performed with the *repeated raster with hold* pointing mode. This mode allows to perform raster maps in any orientation possible, can be repeated if we deem it preferable to long measurements at each raster point, and offers the *hold* mechanism that can be used to interleave calibration measurements inside the raster.

If we find we need to implement chopping and nodding for rasters, we can select the *nodding in raster* pointing mode. This mode implements the *hold* mechanism but does not allow repetition of the raster.

This would however not be necessary here.

Since we are now performing large rasters, we become very sensitive to the SRPE error. We will have to follow attentively all developments of this pointing issue as they can have a major impact on the raster mode.

For scan and freeze-frame maps, we will select the *line scan with hold* pointing mode. One should note that RD4 still contains a number of ambiguities regarding this mode. First its does not mention whether limitations exists regarding the length of the legs (some special scan pointing modes are restricted to 2° while the generic mode allows legs of 20°). Second it mentions that the orientation of the scan is always specified relative to the instrument boresight axes, which is not necessarily what we want. Finally it does not mention what the limit is on the number of legs (and again this limit is stated, and variable, in some of the special scan modes). However this mode is the one that implements the *hold* mechanism in an "intelligent" way, i.e. at the end of legs.

We mention again here that there are no mechanism available to ensure that observers scan their regions of interest with at least two different scanning angle. All data reduction discussion we have had with scanning specialists indicate that this is mandatory to be able to remove striping artefacts. The whole ICC should give some thinking to that problem.

9.6 Internal calibration

Calibration will again consist of the measurement described in Section 5.2. There will be one such calibration at the start of the observation and there should be at least another at towards the end of the observation, using the *inithold* and *finalhold* mechanisms. This becomes quite important now that we are dealing with potentially very long observations. Since the *hold* mechanism is available for both the raster and the scan pointing modes, it can be used to perform intermediate calibration of the responsivity variation.

The frequency and duration of calibration measurements will be decided after FM.

9.7 Data reduction

As of this version, the data reduction process has only been outlined for the normal scanning mode (also called unchopped scanning in RD2 and RD3). I include some thoughts for the other modes, but these should definitely not be considered as more than that, i.e. thoughts.

Although this may lead to repetitions, we break down the description of the data reduction process into three sections, one for each mapping mode. The calibration files identified in these sections are all grouped in Table 12 with the identical mode code (no code means all modes).

9.7.1 Rasters

There is essentially little difference (especially at the level of this document) in the data processing of a 2×2 raster and of an $M \times N$ raster. Thus data reduction follows the steps outlined in Section 8.7.

The only addition that we can probably make is that in large rasters, it is usually possible to measure the flat-field from the data themselves.

9.7.2   Scan maps

As usual, the first step consists in reconstructing the data frames (i.e. the cube of series of SPU-averaged array readouts). The signal is converted to V, and the glitches and saturation events are flagged but not removed.

All frames are now given a label. We now have a smaller set of labels: either we observe the calibration sources (ICS1, ICS2), or we are in the scan, INSCAN, or we are slewing from one leg to the other, SLEW.

All calibration data are analyzed, e.g. differences between the two sources are computed, to provide an estimation of the responsivity and offset drifts during the observation. If possible these drifts are corrected out from the INSCAN data.

At this point it becomes critical to have good astrometric information for all the INSCAN frames. This astrometric information is going to be used to project the frames on a new regular sky grid. We also need to have a precise knowledge of the optical distortion as it is generally corrected when we reproject on the sky.

Given that scan maps usually offer a high redundancy, a number of smarter reconstruction methods can be designed that take that redundancy into account to remove drifts of various origin, and extract the flat-field from the data

9.7.3   Freeze-frame scan maps

In a first approximation, freeze-frame scan maps are raster maps performed faster. We will need some data sorting to remove flag out from the data the frames taken while the chopper is moving back to the first position of its freeze-frame waveform, as well as framed obtained during the deceleration and acceleration periods. Apart from that, raster data reduction should provide a reasonable first guess.

Table 12: Calibration files needed to reduce the mapping AOT.

Parameter name	Mode	Signification and Comments
Gain		We just need to know how many μV per digital units we have in the different gain modes
Glitch and saturation threshold		This more generally should contain the value for the adjustable parameters that future glitch and saturation detection algorithms will use.
Flat-field		Either a series of images, or algorithms to extract it form the data.
Sensitivity		To convert from μV to Jy, for all configurations of the photometer. This could also take the form of a recipe to extract it from the calibration observations performed in the AOT.
Chopper position conversion		The chopping and dithering patterns are described in terms of chopper positions. We need a file that tell us where the virtual aperture falls for each of these positions.
Spatial configuration		To create a correct astrometry, and reproject on the sky we need information on the focal plane geometry, such as distortion, location of gaps in the focal plane, pixel scale.

9.8 Open points

- How do we deal with the chopper? Currently we do not think of offering this option in this mode. We need simulations to define whether chopping in the raster would make sense. We also need these simulations to see if indeed we should restrict the available chop throws.

- How do we deal with repetition? For rasters it may be better to do N-times the same raster rather than a single one with longer integration time at each position. This can be decided with the simulator, and implemented with in the logic by effectively redoing the observation request, transparently for the observer. For scanning this is different. To avoid striping artifacts we should probably repeat the map with a different orientation. If preferred scan angles exist, given that we have square pixels, there will always be at least two possible angles, meaning that it should be possible to concatenate two observations of the same field with these two angles. In freeze-frame mode, repetition with a different angle will mean that we will have to wait a certain number of Operational Days. So it may turn out that it is impossible to schedule freeze-frame observations with "repetition".

- How do we define the virtual aperture for rasters with chopping? Ideally it depends of the chop throw.

- We need the simulator to define quantitative guidelines to select between rasters, rasters with chopper, scan maps and freeze-frame scan maps.

10   Testing the AOT strategy

In principle, the calibration requirements listed in the PACS Calibration Document, and the test sequences that fulfill these requirements should be enough to give us the information we need to select the feasible AOTs. In particular, the noise measurements listed in the PCD are crucial to establish the allowed range for various AOT parameters. The ILT setup is also sufficient to investigate the flat-field stability, which plays an important part in the AOT design.

It remains to be seen whether we should design test sequences whose specific aim would be to test the photometer AOTs. The problem we foresee with the ILT setup is that it only allows for a single point or flat source, or possibly a few point sources, whereas the sky will rather present itself as a collection of point or extended sources. Since we can move a point source in the field of view, there are two aspects of the AOTs that we can specifically test: (1) our ability to reconstruct the flux of a point source from a single staring observation (i.e. how well do we know the PSF), and (2) the 4-point chop-nod AOT.

All other AOTs either require large field of views (to scan in) or complex sources.

Another aspect that can be explored at the ILT level is the calibration scheme. Although it is clear that the environment in the calibration facility will be extremely different from that in space, we can already investigate which of the different schemes envisionned in section **??** is likely to apply.

11 A recap on some open points

This document still contains a number of open questions which make the decision process difficult. They are listed here along with the data/information we need to answer them.

- **flat-field:** Will this be a limiting factor in the observations and should the AOT be designed so as to minimize its influence? This can be investigated during the ILT.

- **Telescope timing:** We need information on the cost, in overhead time, of all telescope manoeuvres (i.e. pointing request, scan request, time needed to reach constant scan speed...) as this play a part in the decision to use a raster or a scan map for a given observation. This should be described in the Herschel documentation although it appears to be ambiguous at the present stage.

- **Telescope quality:** The emissivity of the telescope, and the uniformity of the primary mirror thermal emission on the PACS field of view, as well as its stability in time, impacts the chop/nod strategy, and thus the AOTs and the interactive analysis (especially when chopping has to be combined with scanning). Unfortunately it seems we will only get the final answer in flight.

- **Noise components:** There is not much need to expand this, it is obvious that the various noise sources impact the AOT design. These should be amply characterized during module and instrument level tests.

- **Point Spread Function quality:** In principle, the pixel size is such that it provides an adequate, but not very important, sampling of the PSF. We can expect, as in CAM, that motions of the PSF inside a pixel will produce noticable changes of the flux distribution on the array. Combined with the PACS-specific case that each pixel has a 20-30% blind zone, this can lead to an incorrect reconstruction of the actual PSF flux, while this is at the basis of the staring AOT. Investigation of the PSF properties at ILT should lift some of the uncertainties in this area.

- **Telescope pointing accuracy and jitter:** Jitter affects the observed PSF yet we may need to measure accurately the actual PSF. Jitter along a scan leg can also create artefact in the map reconstruction algorithm. Pointing accuracy may also limit our ability to make sure that a point source does not fall right on a blind area of the focal plane. In principle this should be described in the Herschel documents.

- **Overall mapping efficiency:** The various overheads involved in the operation of the telescope and of the instrument play a part in deciding whether an AOT is more efficient that another. Unfortunately all these will be know rather late in the development.

- **Responsivity stability:** We need to know how far and how fast the bolometer can drift out of a calibrated state. This tells us which calibration scheme has to be implemented. In turn this may impact on the AOT design, specifically those that require long operations such as the scanning one. This should be known at ILT, if not earlier.