HERSCHEL SPACE OBSERVATORY

Announcement of Opportunity for Key Programmes

SPIRE PACS Parallel Mode Observers' Manual

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Chapter 1. Introduction

1.1. Purpose of document

The SPIRE PACS Parallel Mode Observers' Manual is intended to support astronomers in the definition of their observations using a special mode, where two of the science instruments on board the Herschel Space Observatory are operating simultaneously.

This document is mainly focusing on the description of the Parallel Mode Astronomical Observing Template (AOT) and its optimum use for scientific programmes. Instrument descriptions, scientific capabilities and detailed performance estimations of the two involved instruments are given separately in the PACS Observers' Manual and in the SPIRE Observers' Manual.

This version is written to support the Key Programmes call for Herschel observing proposals by the European Space Agency (ESA) in 2007.

1.2. Background

1.2.1. Mission characteristics

The Herschel Space Observatory is an ESA cornerstone mission, for high spatial resolution observations in the FIR and sub-millimeter regime, to be launched in 2008 aboard an Ariane 5 rocket together with Planck. It will enter a Lissajous 700 000 km diameter orbit 1.5 million kilometers away from Earth at the second Lagrange point of the Earth-Sun system.

The mission is named after Sir William Herschel, who discovered the infrared radiation in 1800.

It will be the first space observatory to cover the full far-infrared and submillimetre waveband. It will perform photometry and spectroscopy in the 57-672 µm range, with its 3.5m diameter radiatively cooled telescope, while its science payload complement of three instruments is housed inside a superfluid helium cryostat.

Herschel will be operated as an observatory facility offering three years of routine observations, which will be available for the entire scientific community. Roughly two thirds of the observing time are "open time", and will be offered through a standard competitive proposal procedure.

1.2.2. Science instruments of Parallel Mode in a nutshell

The Photodetector Array Camera & Spectrometer (PACS) is one of the three science instruments of the Herschel observatory. PACS provides the Herschel Space Observatory with the capabilities for spectroscopy and imaging/photometry in the 57-210 µm range. The PACS instrument is equipped with two sub-instruments which offer two basic mutually exclusive modes:

- Imaging dual-band photometry (60-85 µm or 85-130 µm and 130-210 µm) over a field of view of 1.75'x3.5', with full sampling of the telescope point spread function (diffraction/wavefront error limited). The PACS photometer has two monolithic bolometer matrices operating at 300 mK temperature. The blue channel has a 32x64 pixels arrays, while the red channel is equipped with a 16x32 pixels array.

- Integral-field spectroscopy between 57 and 210 µm with a resolution of ~75-300km/s and instantaneous coverage of ~1500 km/s, over a field of view of 47"x47" projected to 5x5 spatial pixels. The spectrometer employs two Ge:Ga photoconductor arrays (low and high stressed) with 16x25 pixels on which the 16 spectral elements of the 25 spatial pixels are imaged.

SPIRE contains a three-band imaging photometer and an imaging Fourier Transform Spectrometer (FTS), both of which use bolometer arrays operating at 0.3 K and are coupled to the telescope by hexagonally close-packed conical feedhorns. Three bolometer arrays are used for broad-band photometry ($\lambda/\Delta\lambda$ ~3) in spectral bands centred on approximately 250, 350 and 500 µm. The same 4 x 8 arcmin field of view is observed simultaneously in these three bands through the use of two fixed dichroic beam-splitters. Signal modulation can be provided either by SPIRE's two-axis Beam Steering Mirror (BSM) or by scanning the telescope across the sky. An internal thermal source is available to provide a repeatable calibration signal for the detectors (and can also be seen by the FTS detectors).

The FTS has spatially separated input and output ports. One input port views a 2.0 arcminute diameter field of view on the sky and the other is fed by an on-board reference source. Two detector arrays at the output ports cover overlapping bands of 194-324 µm and 316-672 µm. The FTS spectral resolution is set by the total optical path difference, and can be adjusted between 0.04 and 1 cm^{-1} (corresponding to $\lambda/\Delta\lambda$ = 1000 - 40 at 250 µm).

1.3. Acronyms

- `AOR : Astronomical Observation Request`
- `AOT : Astronomical Observation Template`
- `DTCP : Daily TeleCommunications Period`
- `ESA : European Space Agency`
- `FOV : Field-Of-View`
- `HSpot: Herschel planning observations tool`
- `ICC: Instrument Control Centre`
- `ICS: Internal Calibration Source`
- `OD: Observation Day`
- `PACS : Photodetector Array Camera & Spectrometer`
- `PM : SPIRE PACS Parallel Mode`
- `SPIRE : Spectral and Photometric Imaging Receiver`

Chapter 2. Observing in SPIRE PACS Parallel Mode

2.1. Definition of Parallel Mode

In Parallel Mode (PM) PACS and SPIRE are operating in photometry mode simultaneously, carrying out large-area mapping observations. PACS is taking data in its red band (130-210 µm) and in one of the blue bands (60-85 µm or 85-130 µm) while SPIRE is observing in its three photometric bands (250, 350 and 500 µm).

The SPIRE PACS Parallel Mode is treated as a 4th Herschel instrument, i.e. it has its own Astronomical Observing Template (AOT), its own user interface in HSpot and the two instruments are operated in a way that the spacecraft infrastructure is optimally used.

The potential advantage of PM is ensured by the compatibility of the two instruments and their operating modes. In practice, simultaneous observations in five bands are made possible without significant degradation in instrument performance. However, considering the fact that the PACS and SPIRE integration times are identical, the relative instrument sensitivities have to be carefully inspected to judge the real scientific benefit of using PM.

The PACS instrument has to apply a higher science data compression ratio with respect PACS prime operations in order to make sure the increased data rate in five bands is still within the allowed limits. The compression ratio is still not precisely known but some loss of sensitivity and spatial resolution is expected. In the first order this is due to the beam smearing effect along the scan direction when bolometer readouts are averaged on-board Herschel.

Parallel Mode will be used during dedicated Observation Days (OD) of 21 hours, although no single observation could last longer than 18 hours. The reason for this is to allow uninterrupted observations with the PACS and SPIRE photometers to reduce operational overheads caused by cooler recycling or switching between subinstruments. Photometers cooler recycling takes about 2 hours per instrument, and will be carried out during the Daily Telecommunication Period (DTCP) prior to a dedicated PM observing window. As the hold time of the identical PACS and SPIRE coolers is expected to be more than 48 hours, the preferred and most effective use of PM is to carry out observations during windows of 2 days.

2.2. Scientific benefits of SPIRE PACS Parallel Mode

For programmes involving shallow galactic surveys over large areas of sky, Parallel Mode offers a major efficiency gain or major additional scientific data with respect two separate PACS and SPIRE coverages. For other mapping programmes like deep galactic surveys or shallow extragalactic surveys, there may be some advantages with careful design of mosaicking, although not so great.

2.2.1. Large area shallow galactic surveys

For very large shallow programmes, where the requested coverage is typically in the order of 100 square degrees or more, the observer could save a significant time compared to using the two instruments separately and covering the survey area twice. For these programmes the PACS observations to be obtained without compromising the sky coverage. This is the most likely instance in which Parallel Mode could be beneficial.

2.2.2. Deep galactic surveys

Deep surveys of nearby molecular clouds mapped with SPIRE could have a benefit of PM mode. Instead of doing SPIRE observations only, it could be conceivable that PACS is operated in parallel without compromising SPIRE data quality, providing a shallow PACS survey of the complete regions. This would effectively provide additional data for the same observing time. The benefits in terms of mapping efficiency and additional data would not be as great as for a larger shallow survey, but PACS data could be worthwhile nonetheless.

2.2.3. Deep extragalactic surveys

One could assume the survey area of deep extragalactic mapping programmes is considerable smaller than for galactic surveys. For such a programme the Parallel Mode gain on mapping efficiency is not a great benefit. These observations will cover a range of depths where both PACS and SPIRE sensitivities are demanding. As with the galactic surveys, it is possible that PACS could be operated in parallel to provide additional data but in considerable lower sensitivities.

2.3. Additional benefits of Parallel Mode

Operating PACS and SPIRE together increases the load on the helium tank of Herschel by much less than a factor of two, because the total load is largely from the cryostat parasitics. Parallel operations is thus very favourable in terms of science per litre of helium what could increase the overall lifetime of the observatory.

Observations made in PM will have more accurate relative PACS/SPIRE astrometry, because the relative angular offsets between the two arrays are fixed and accurately known.

The efficiency of scientific mission planning is also increased because the scheduling of PACS and SPIRE observations of the same sky area can be done within a single block. This reduces the total telescope slew time over the mission lifetime in favour of science time.

2.4. Parallel Mode sensitivities

Detailed description of photometer sensitivity calculations and sensitivity numbers are provided in the corresponding Observers' Manuals (see PACS Observers' Manual Section 3.4.4 and SPIRE Observers' Manual Chapter 3).

In this section sensitivity numbers are given (Table 2.1) specific for the Parallel Mode. The PM AOT (see section 2.5) allows to influence the depth of the observation only in one way, the observer can choose between scan speed 60"/second (fast mode) or scan speed 20"/second (slow mode). In the table the first column summarizes sensitivities for the fast mode and the second column is given for the deeper slow mode. To a first order the sensitivity in scan mode scales with the inverse of the square root of the on-source observation time (the source crossing time), therefore the gain in depth if changing from fast to slow mode is about a factor of 1.7.

Sensitivities provided in Table 2.1 are applicable for all PM observations irrespective the map size, however, minor variations could be noticed when running the HSpot time estimator for Parallel Mode.

Table 2.1. The SPIRE PACS Parallel Mode predicted 1-σ sensitivities for a point source in mJy, calculated for the two scan speeds and for a single map coverage

Scan speed	60''/second	20''/second
PACS 60-85 µm	17.6	10.2
PACS 85-130 µm	19.0	11.0
PACS 130-210 µm	26.8	15.5
SPIRE 250 µm	12.8	7.4

Scan speed	**60''/second**	**20''/second**
SPIRE 350 µm	17.6	10.2
SPIRE 500 µm	14.9	8.6

2.5. SPIRE PACS Parallel Mode AOT

Detailed description of "parent AOTs" from which the SPIRE PACS Parallel Mode AOT is derived can be found in the corresponding Observers' Manuals (see PACS Observers' Manual Section 4.1.3.2 and SPIRE Observers' Manual Section 4.1.3).

2.5.1. Scan mapping mode

The Parallel Mode AOT is offered with only one observing mode. Scanning is the most compatible operating mode of PACS and SPIRE where scanning strategy has been made optimum for both instruments. Scan maps are the default for PACS to map large areas of the sky, for galactic as well as extragalactic surveys. SPIRE always operates is scan mode for large mapping observations.

Scan maps are performed by slewing the spacecraft at a constant speed along parallel lines to cover a large area. The lines follow great circles on the sphere which approximates parallel lines over short distances. When finishing a scan leg, the spacecraft has to perform a turn maneuvre and continue observations along the next scan leg in the opposite direction. The time required for this turn is about half a minute.

Scan mapping does not make use of chopping, the signal modulation being provided by the spacecraft motion.

Two scan speeds are offered: the fast mode applies 60 arcseconds per second, the slow mode is performed at 20 arcseconds per second. Applying the fast mode (default value) a serious degradation of the PACS PSF is expected due to on-board data averaging and detector memory effects.

It is suggested to perform two scan maps of the same area, one with nominal coverage, the other with orthogonal coverage in order to remove more efficiently the stripping effects due to the 1/f noise. For this purpose two AORs shall be concatenated in HSpot to be performed with a different scan direction.

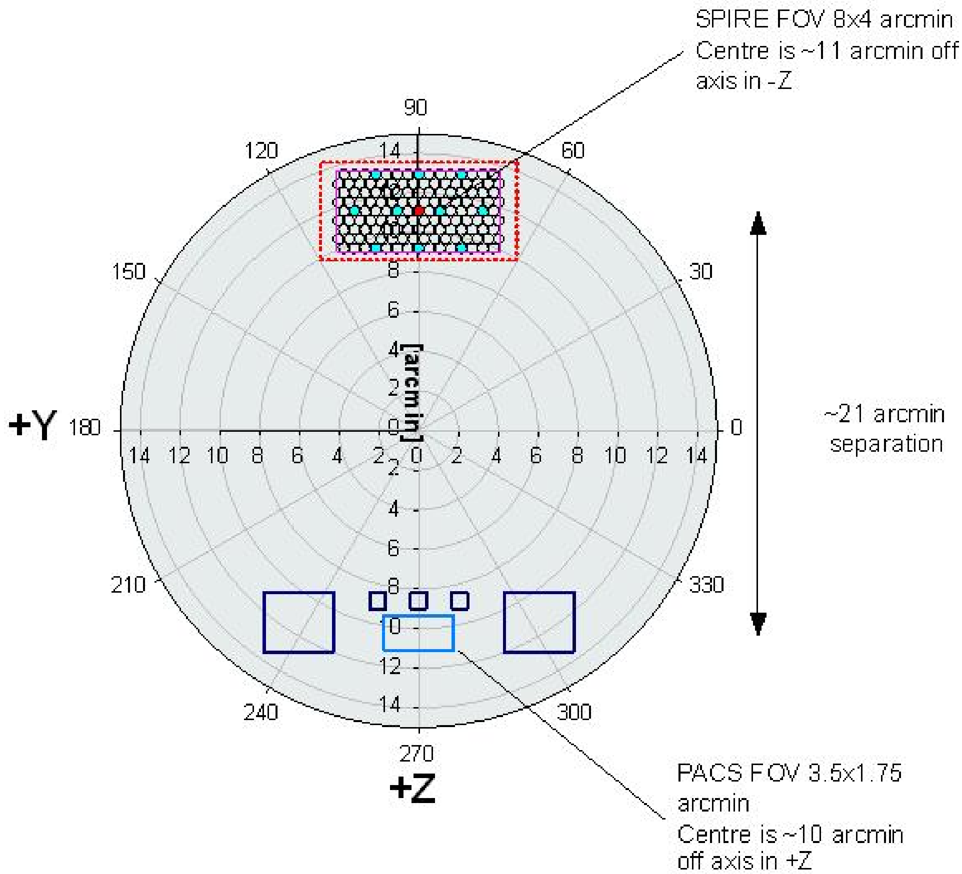

Figure 2.1. PACS and SPIRE footprints overlayed on the Herschel focal plane image. The field-of-views of the two instruments are separated by 21 arcmin respectively.

As the SPIRE arrays are not fully filled the telescope scans in PM are carried out at 42.4 degrees (in "Nominal" scan direction) with respect to short axis of the arrays (angle from instrument +Z-axis to +Y-axis - see Figure 2.1) . This angle, along with the step size between consecutive lines of 155 arcsec, has been selected to provide fully sampled maps for both instruments. The step size is calculated such that PACS performs homogeneous coverage over the mapping area, similar as described in PACS Photometer AOT Scan map mode (see PACS Observers' Manual Section 4.1.3.2). This small step size for SPIRE results a high oversampling factor and a gain in sensitivity without compromising map uniformity (see SPIRE Observers' Manual Section 4.1.3).

2.5.2. Setting up AOT parameters

As a first step, the PACS band has to be selected in the blue channel (60-85 µm or 85-130 µm). The other four PM bands are fixed.

In the second step, selecting the scan speed the observer could have control over the sensitivity of the measurement. Note, there is no possibility to repeat PM maps within one single observation request (AOR) to enhance the survey depth.

Note
The depth of observation in PM mode can be controlled by three ways: (i) adjust scan speed; (ii) add "Nominal" and "Orthogonal" coverages on the same area of the sky; (iii) repeat AORs.

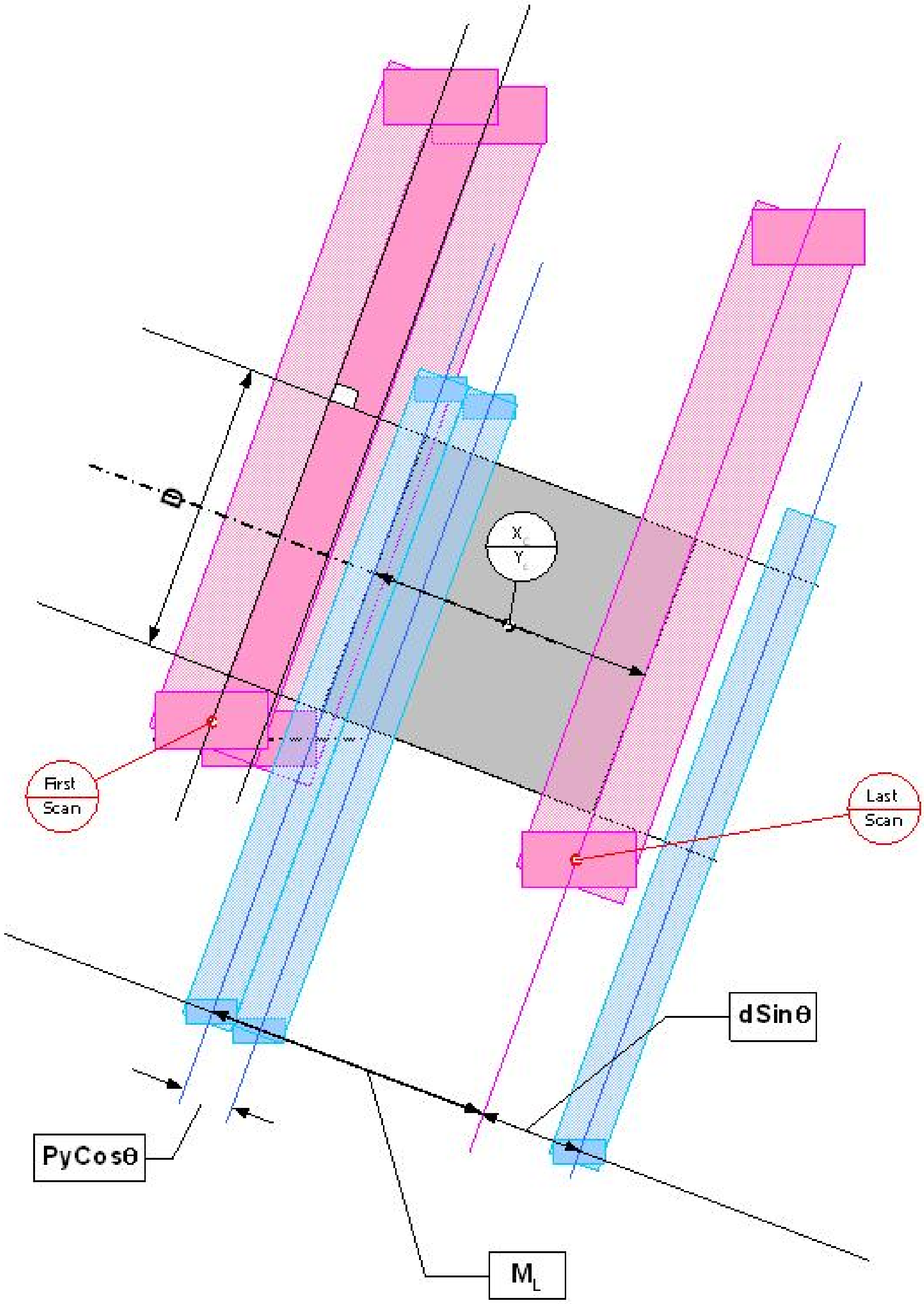

Figure 2.2. Illustration of Parallel Mode scanning scheme. The grey area is the common PACS-SPIRE survey field what the observer specifies in HSpot. The scanning angle with respect the arrays' short axis is 42.4 degrees. Blue colour represents the PACS scaning path, red colour is used for SPIRE .

The dimensions of the area to be covered is used to set by the length and height of the common PACS SPIRE survey area (see Figure 2.2). The figure illustrates how the common PACS SPIRE survey area - the grey box - is actually built up. The number of scans required to cover the common area is higher than would be required in a single instrument coverage. The number of extra scans and the required length of the scan legs both depend on the scan angle and the footprints separation. Taking into account the 42.4 degrees scan angle and the fixed 21 arcminute separation of the PACS and SPIRE footprints, the PM observations perform five or six extra scans and extend the scan leg length with 22 arcminutes respectively. Hence the actual area observed with each instrument will be bigger than what was requested.

Note
Using the PACS Photometer AOT the PM settings can be reproduced in scan map mode. In this configuration you have to set high or medium scan speed, 155 arcseconds cross-scan step and 42.4 degrees orientation angle in "Array" or "Array with sky constraint" reference frame.

The centre of the common survey area is at the coordinates given by the target position. The map size along a scan leg can be specified by the map "Length" parameter. In perpendicular direction, the common survey size is defined by the "Height" parameter. In case the scan direction is set to "Orthogonal" then the observer has to change the "Length" and "Height" parameters, the spacecraft will perform an observation along -42.4 degrees scan angle over the survey area specified for "Nominal" direction. The pairs of nominal and orthogonal AORs can be concatenated in HSpot (see further details in the HSpot Users' Guide). An illustration how a Parallel Mode AOR footprint is visualized in HSpot can be seen in Figure 2.3 and in Figure 2.4. Pink represents the PACS and green the SPIRE footprint, the observer requested common survey area is painted by both instruments.

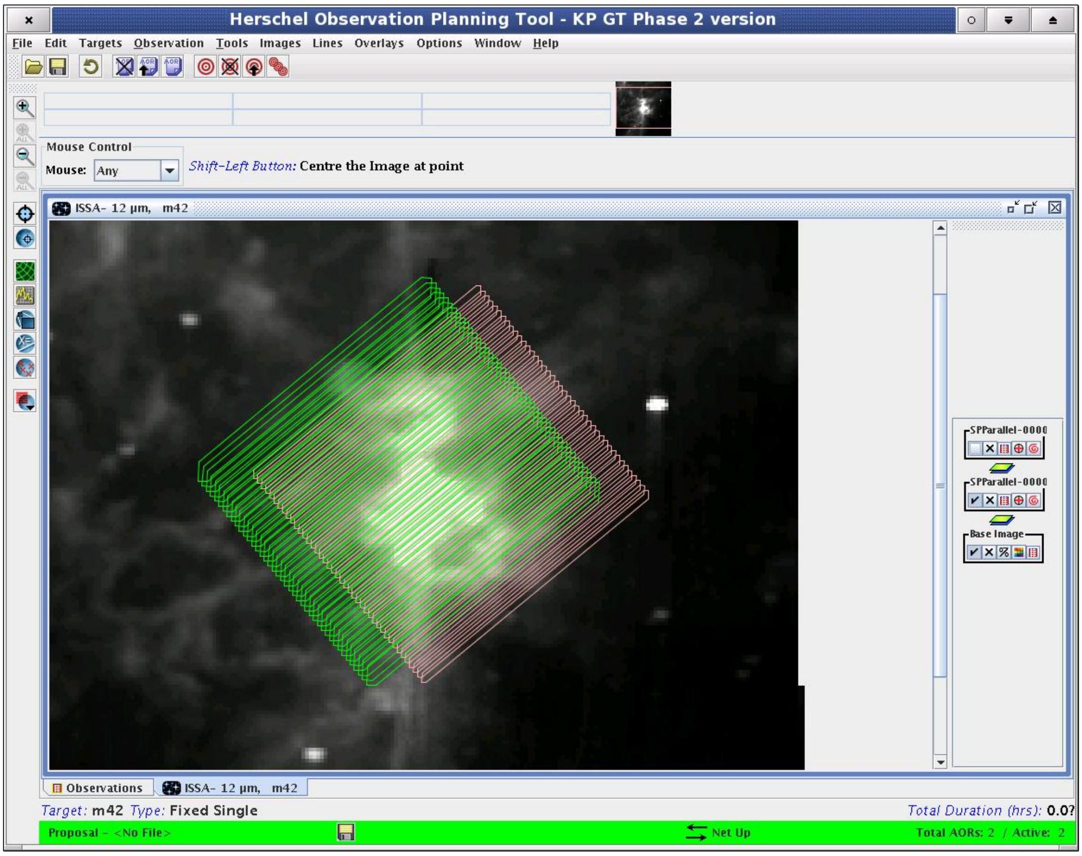

Figure 2.3. Parallel Mode footprint image example. Part of M42 is imaged in "Nominal" PM coverage.

Tip
It is recommended to concatenate PM AORs if the same target applies for all measurement in a sequence. In such a group of observations the observatory overhead will be charged only once and HSpot will render this time to the first AOR of the concatenation chain.

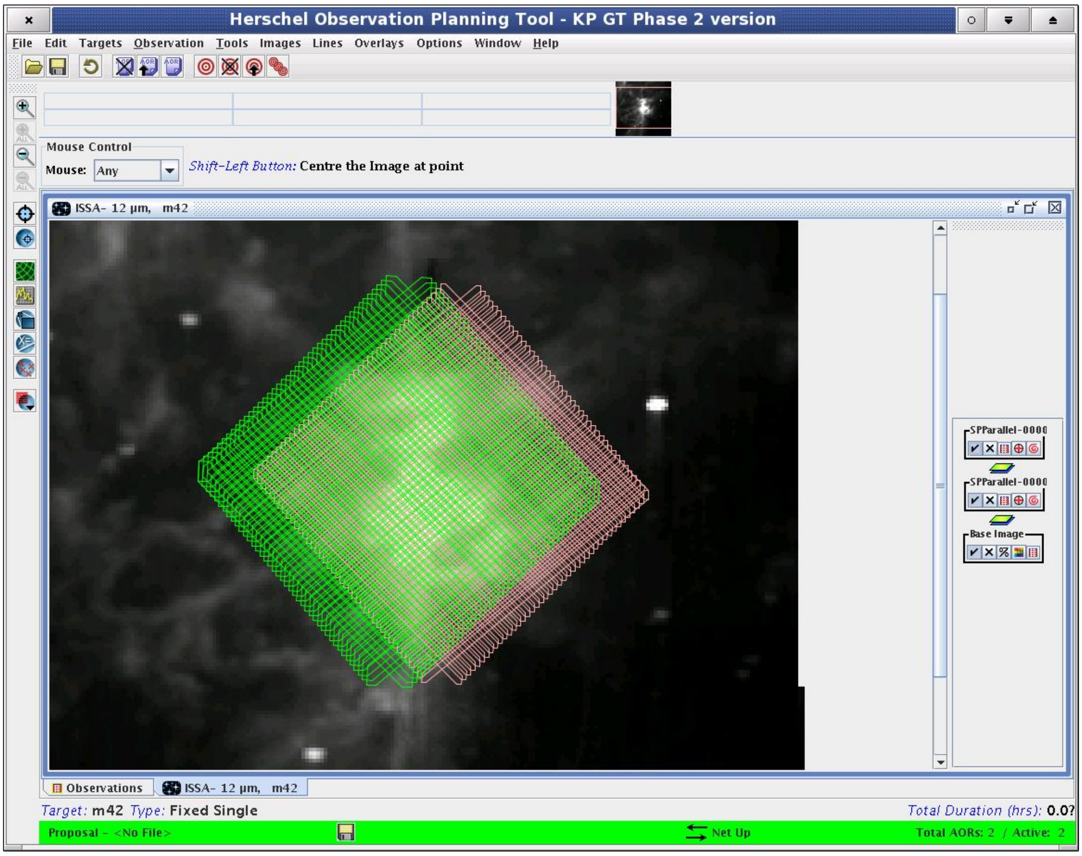

Figure 2.4. Parallel Mode footprint image example. Part of M42 is imaged in "Nominal" plus "Orthogonal" PM coverages.

As the map is carried with a specific angle of the arrays and because the orientation of the array on the sky changes as Herschel moves in its orbit then the actual coverage of the map will rotate about the requested centre of the map except for sources close to the ecliptic plane. However, in order to cover specific rectangular (elongated) areas in the sky, a constraint on the orientation of the scan map in the sky can be introduced by selecting a range for the 'map position angle', i.e. the angle from the celestial equatorial north to the scan line direction, counted positively east of north. This corresponds to the option 'Array with Sky Constraint' in HSpot.

Setting a Map Orientation constraint means that your observation will not be able to be performed during certain periods, hence number of days that your observation can be made will be reduced from the number of days that the target is actually visible. In setting a constraint the observer needs to check that it is still possible to fit the observation within a visibility window or orientation constraint was blocked out all dates. Note also that parts of the sky do not change their orientation with respect to the array and therefore it is not possible to set the orientation of the map in certain directions (close to the ecliptic plane) as the array is orientated in a restricted direction on the sky.

> **Note**
> Setting constraints on when the observation can be performed make scheduling and the use of Herschel less efficient hence observer will charged extra overheads to compensate (see Herschel Observatory Manual).

Table 2.2. User input parameters for SPIRE PACS Parallel Mode AOT

Parameter name	Signification and comments
Filter	Which of the two filters from the PACS blue channel to use (60-85 µm or 85-130 µm).
Map Orientation	The reference frame for the scan map orientation, either "Array" or "Array with Sky Constraint". This can be entered, by selecting a range of map orientation angles for the observation to take place.
Angle from/to	The constraint on map angle is the angle measured from the equatorial North to the direction of the scan leg calculated East of North and towards the scan direction of the map's first scan leg.
Scan speed	Slew speed of the spacecraft, fast mode (60 arcsec/s), or slow mode (20 arcsec/s).
Length	Length of the common survey area parallel the scan direction in arcminutes, the maximum length is 1173 arcmin.
Height	Size of the common survey area in perpendicular direction in arcminutes, the maximum height is 232 arcmin.
Scan Direction	This parameter defines the scan angle along which the spacecraft builds up the scan legs. In "Nominal" direction the scan angle is 42.4 degrees, in "Orthogonal" direction the angle is set to -42.4 degrees.

Chapter 3. Changes to the document

In this chapter most important changes are listed with respect the previous version 1.0 of the SPIRE PACS Parallel Mode Observers' Manual.

- Latest photometer sensitivities have been adopted in Table 2.1
- Added Figure 2.4 and updated Figure 2.3
- Parameter limit "Height" has been changed to 232 arcmin in Table 2.2