



## **Announcement of Opportunity for Open Time**

# **SPIRE PACS Parallel Mode Observers' Manual**

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# **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 [SPIRE Observers' Manual](#) and in the [PACS Observers' Manual](#).

This version is written to support the first in-flight Open Time call for Herschel observing proposals by the [European Space Agency \(ESA\)](#) in 2010.

## 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-millimetre regime, launched on 14<sup>th</sup> of May 2009 aboard an Ariane 5 rocket together with Planck. It entered a Lissajous 700000 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 is the first space observatory to cover the full far-infrared and sub-millimetre waveband. It performs photometry and spectroscopy in the 57-671  $\mu\text{m}$  range, with its 3.5 m diameter radiatively cooled telescope, while its science payload complement of three instruments is housed inside a superfluid helium cryostat.

Herschel is operated as an observatory facility offering three years of routine observations, which is 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. Parallel Mode science instruments in a nutshell

The Spectral and Photometric Imaging Receiver (SPIRE) is one of the three science instruments of the Herschel Space Observatory. It contains an imaging photometer and an imaging Fourier Transform Spectrometer (FTS), both of which use bolometer arrays operating at 300 mK and are coupled to the telescope by hexagonally close-packed conical feedhorns. The two sub-instruments offer two basic, mutually exclusive modes:

- Three bolometer arrays are used for broad-band photometry ( $\lambda/\Delta\lambda \sim 3$ ) in spectral bands centred on approximately 250, 350 and 500  $\mu\text{m}$ . A 4'x8' field of view is observed simultaneously in the 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
- The FTS has spatially separated input and output ports. One input port views a 2' diameter field of view on the sky and the other is fed by an on-board reference source, in order to null the telescope emission. Two detector arrays at the output ports cover overlapping bands of 194-324  $\mu\text{m}$  and 316-671  $\mu\text{m}$ . The FTS spectral resolution is set by the total optical path difference, and can be adjusted between 0.04 and 0.83  $\text{cm}^{-1}$  (corresponding to  $\lambda/\Delta\lambda = 1000 - 40$  at 250  $\mu\text{m}$ ). The same internal thermal source used for the photometer is seen by FTS detectors as well.

The Photodetector Array Camera & Spectrometer (PACS) provides Herschel with the capabilities for spectroscopy and imaging/photometry in the 57-210  $\mu\text{m}$  range. The PACS instrument is equipped with two sub-instruments:

- Imaging dual-band photometry (60-85  $\mu\text{m}$  or 85-130  $\mu\text{m}$  and 130-210  $\mu\text{m}$ ) 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  $\mu\text{m}$  with a resolution of ~75-300 km/s and instantaneous coverage of ~1500 km/s, over a field of view of 47"x47" projected onto 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.

## 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
- PSF : Point Spread Function
- PV : Performance Verification Phase
- SPIRE : Spectral and Photometric Imaging Receiver

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# Chapter 2. Observing in SPIRE PACS Parallel Mode

## 2.1. Definition of Parallel Mode

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

The SPIRE PACS Parallel Mode is treated as a 4<sup>th</sup> 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 advantage of Parallel Mode 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 Parallel Mode.

In Parallel Mode, the detectors' sampling frequency of the SPIRE instrument is reduced to 10 Hz, in respect to the 18.2 Hz of the SPIRE-only operations. Observations performed during the PV phase demonstrated that this does not affect the quality of SPIRE data, especially when scanning at 20"/s (slow mode). However, scanning at 60"/s (fast mode) has a small impact, mostly on glitches detection, removal and timeline reconstruction, and, as a second order effect, on beam smearing.

The PACS instrument applies an additional data compression with respect to PACS-prime operations, in order to make sure that the data rate in the five bands (3 for SPIRE and 2 for PACS) stays within the allowed limits. In the blue channel, data frames are averaged on-board 8 by 8, but the compression is left unchanged; in the red channel, a 4 by 4 frames averaging is applied. As a consequence, in Parallel Mode the PSF is more elongated in the blue channel than in PACS-prime scan mapping.

Parallel Mode will be used during dedicated Observation Days (ODs) of  $\sim 21$  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 sub-instruments. Photometers cooler recycling takes about 2.5 hours each and it is run almost in parallel for the two instruments (30 minutes apart). It is carried out during the 3 hours of the Daily Telecommunication Period (DTCP), prior to a dedicated Parallel Mode OD. The cooler hold time is  $\sim 48$  hours for SPIRE and up to  $\sim 60$  hours for PACS: the preferred and most effective use of Parallel Mode is to carry out observations during windows of 2 days.

## 2.2. Scientific benefits of Parallel Mode

As mentioned earlier, there is no evident degradation of SPIRE data between the SPIRE-prime and the Parallel Mode configuration, as long as the on-source integration time is the same. This implies that when the program involves large areas (bigger than 30'x30') and the observer is interested mainly in SPIRE data, it would be advantageous to use Parallel Mode in respect to SPIRE-only observation, basically obtaining PACS data for free. In order to get the same on-source integration time as the SPIRE-only observation, the observer might require to repeat the observation multiple times, including cross-scans observations.

Instead, for PACS we do see a degradation of the PSF in respect to PACS-only observations, due to the higher compression factor in Parallel Mode. Hence, if the program mainly relies on PACS-data, it might be better to schedule PACS and SPIRE observations separately.

As a consequence, for programmes involving shallow galactic surveys over large areas of sky, Parallel Mode offers a major efficiency gain and major additional scientific data with respect to two

separate PACS and SPIRE coverages. For other mapping programmes like deep galactic surveys or extragalactic surveys, there may be some advantages with careful design of mosaicking, although not so great.

### 2.2.1. 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. 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 will have a benefit using Parallel Mode mode. Instead of doing SPIRE observations only, it is 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

For such a programme the Parallel Mode gain on mapping efficiency is not a great benefit. This is particularly true under the assumption that the survey area of deep extragalactic mapping programmes is considerable smaller than for galactic surveys. Moreover, 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.

### 2.2.4. Additional benefits of Parallel Mode

Operating SPIRE and PACS 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 favorable in terms of science per litre of helium, increasing the overall lifetime of the observatory.

Moreover, observations made in Parallel Mode will have more accurate relative PACS/SPIRE astrometry, because the relative angular offsets between the two arrays are fixed and accurately known and the pointing error will be the same for the two instruments throughout the observation.

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 favor of science time.

## 2.3. Parallel Mode sensitivities

Detailed description of photometer sensitivity calculations and sensitivity numbers are provided in the corresponding Observers' Manuals (see Chapter 4 of the [SPIRE Observers' Manual](#) and Chapter 3 of the [PACS Observers' Manual](#)).

In this section, sensitivity numbers are given specific for the Parallel Mode (Table 2.1). The Parallel Mode AOT (see Section 2.4.2) allows to influence the depth of the observation only in one way: the observer can only choose the scan speed: 60"/s (fast mode) or 20"/s (slow mode). In Table 2.1, the second column summarizes sensitivities for the fast mode and the third column reports sensitivities 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.

Table 2.1 reports 1- $\sigma$  instrument noise for a point source: values are applicable to all Parallel Mode

observations irrespective of the map size. Note the difference between "Nominal" and "Orthogonal" scan directions, due to the different scan leg separation (see Section 2.4.1).

**Table 2.1. The SPIRE PACS Parallel Mode 1- $\sigma$  instrument noise for a point source, calculated for the two scan speeds and for a single map coverage. Units are mJy in beam.**

Scan direction	Nominal		Orthogonal	
	60"/s	20"/s	60"/s	20"/s
SPIRE 500 $\mu\text{m}$	15.0	8.7	14.4	8.3
SPIRE 350 $\mu\text{m}$	10.5	6.0	10.0	5.8
SPIRE 250 $\mu\text{m}$	12.6	7.3	12.1	7.0
PACS 130-210 $\mu\text{m}$	47.0	27.3	45.2	26.3
PACS 85-130 $\mu\text{m}$	24.7	14.3	23.8	13.8
PACS 60-85 $\mu\text{m}$	21.0	12.2	20.2	11.7

## 2.4. 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 Section 3.2.1 of the [SPIRE Observers' Manual](#) and Section 4.1.3.2 of the [PACS Observers' Manual](#)).

### 2.4.1. Scan mapping mode

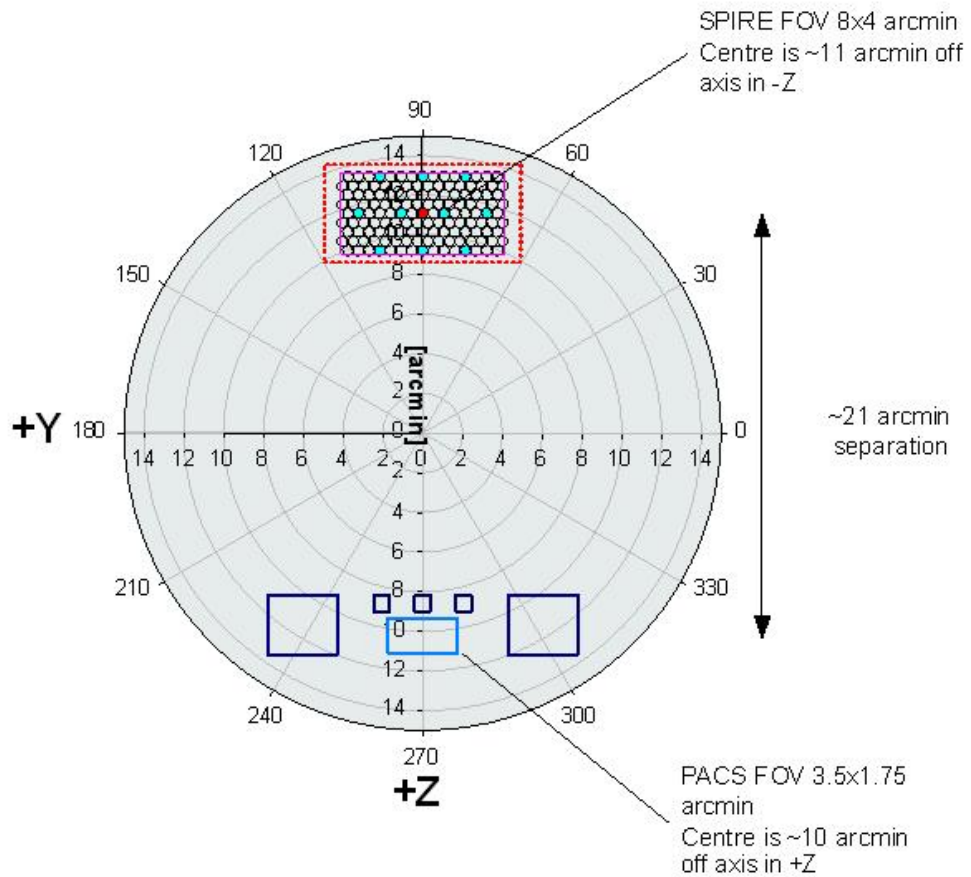
The Parallel Mode AOT is offered with only one observing mode: scanning. It is the only compatible mode for operating SPIRE and PACS simultaneously: in fact, scan mode is the only option for both SPIRE and PACS to map large areas of the sky, even when they are operated alone.

The scanning strategy has been optimized for both instruments. 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 maneuver and continue observing along the next scan leg in the opposite direction: the time required for this turn is about half a minute. Note that scan mapping does not make use of chopping, being the signal modulation 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), PACS PSF is degraded due to on-board data averaging and detector memory effects.

The Parallel Mode AOT does not allow to do cross-scans in a single observation. However, it is strongly suggested to perform two scan maps of the same area, one with nominal coverage and the other with orthogonal coverage, in order to remove more efficiently the stripping effects due to the 1/f noise and to get better coverage redundancy, especially for SPIRE. For this purpose two AORs shall be concatenated in HSpot to be performed with a different scan direction. An example of the better coverage achievable using cross-scans is presented in Figure 2.8.





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

As the SPIRE arrays are not fully filled, the telescope scans in Parallel Mode are carried out at  $+42.4^\circ$  ("Nominal" scan direction) or  $-42.4^\circ$  ("Orthogonal" scan direction) with respect to short axis of the arrays (angle from instrument +Z-axis to +Y-axis, see Figure 2.1). In order to provide homogeneous coverage over the mapping area and to optimize PACS performances in the two scan directions (see Section 4.1.3.2 of the [PACS Observers' Manual](#)), the step size between consecutive lines is 168" when scanning in the "Nominal" direction and 155" when scanning in the "Orthogonal" one. This small step size for SPIRE (being 348" the default one SPIRE-only large scan maps, see Section 3.2.1 of the [SPIRE Observers' Manual](#)) results in a high oversampling factor and a gain in sensitivity, without compromising map uniformity.

## 2.4.2. Setting up AOT parameters

When selecting "SPIRE PACS Parallel Mode" from the "Observation" menu in HSpot (see [Chapter 14 of the HSpot Users' Guide](#)), a window like the one shown in Figure 2.2 appears on the screen.

As a first step, the PACS band has to be selected in the blue channel (60-85  $\mu\text{m}$  or 85-130  $\mu\text{m}$ ). The other four Parallel Mode bands are fixed.

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

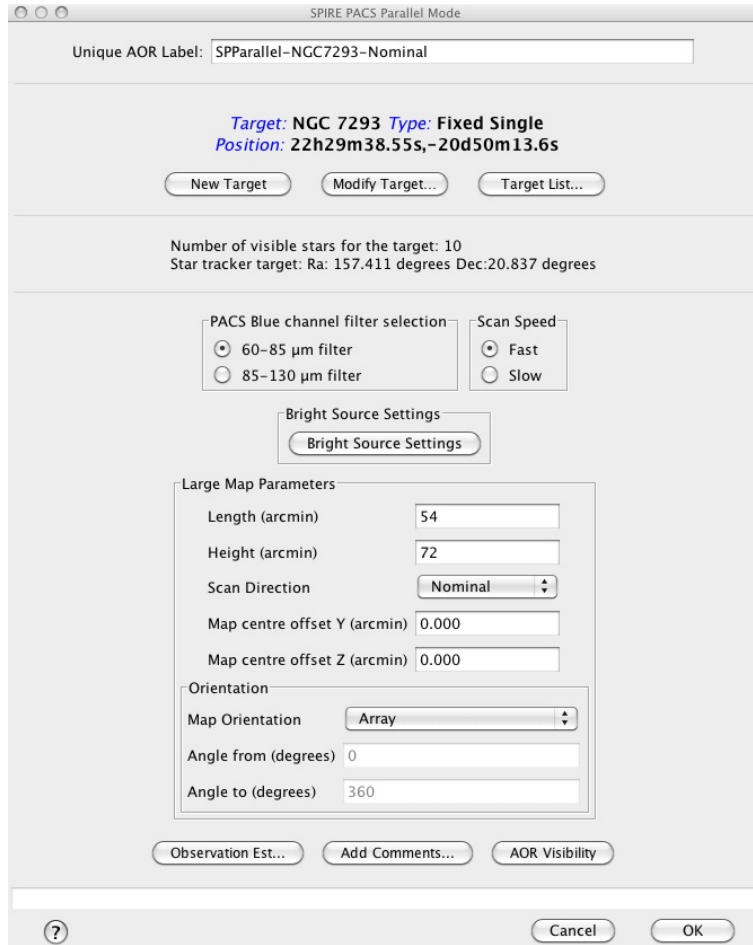


Figure 2.2. HSpot window for setting up Parallel Mode AOR



**Note**

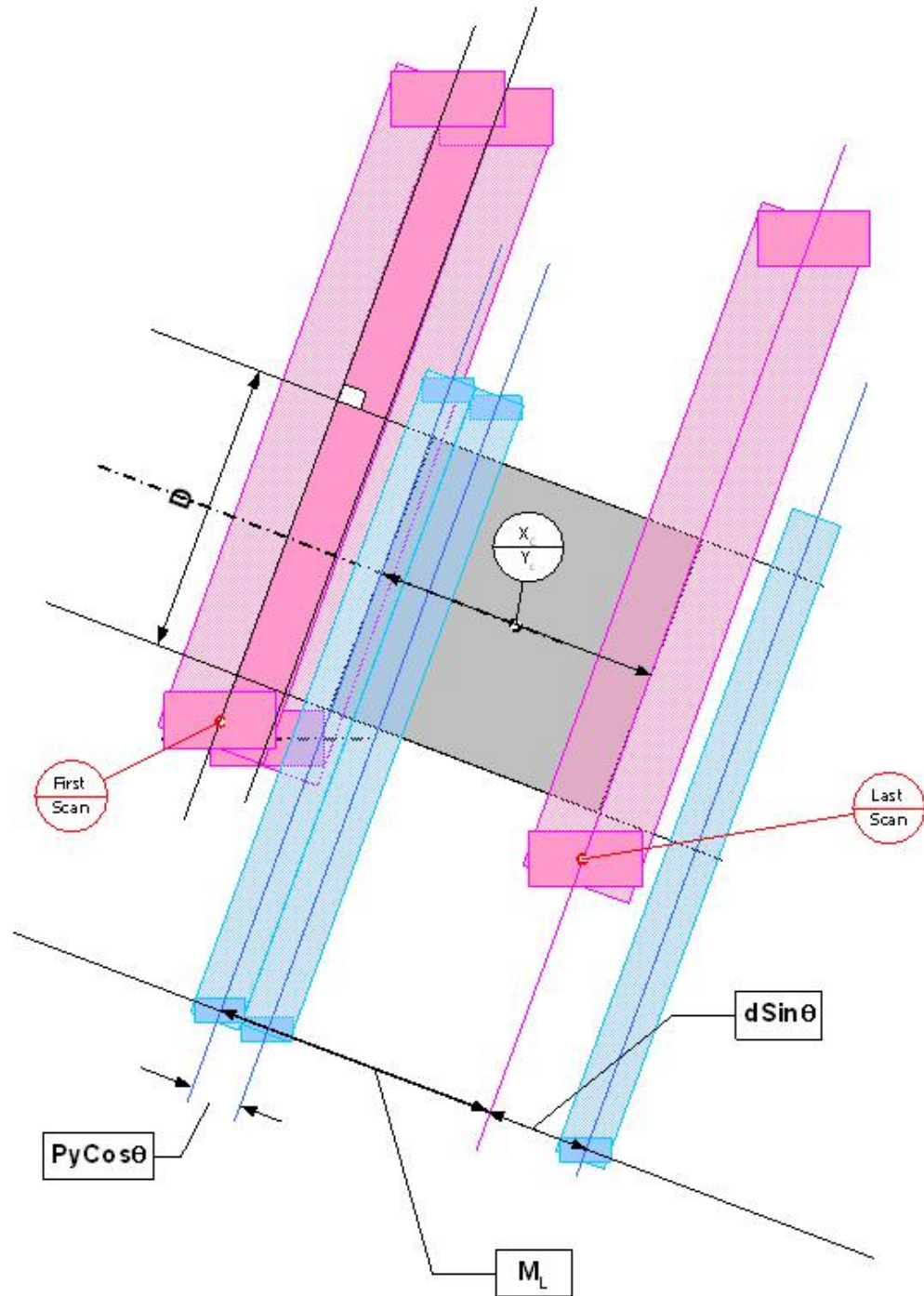
The depth of observation in Parallel Mode mode can be controlled by three ways: (i) adjust scan speed; (ii) add "Nominal" and "Orthogonal" coverages on the same area of the sky; (iii) repeat AORs.

The dimensions of the area to be covered is set by the length and height of the common SPIRE-PACS survey area (see Figure 2.3). The figure illustrates how the common SPIRE-PACS 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° scan angle and the fixed 21' separation of the SPIRE and PACS focal planes' footprints on the sky, the Parallel Mode observations perform five or six extra scans and extend the scan leg length with 22' respectively. Hence, the actual area observed with each instrument will be bigger than what was requested.



**Note**

Using the SPIRE Photometer AOT, the Parallel Mode settings can be reproduced in scan map mode simply enlarging the requested area by ~15' in both length and height. This applies to PACS scan map mode too; however, in this case the observer must set a scan step of 168" and +42.4° orientation angle in "Array" or "Array with sky constraint" reference frame to get the same Parallel Mode "Nominal" scan direction coverage. The scan step must be set to 155" and the orientation angle to -42.4° to reproduce the Parallel Mode "Orthogonal" scan direction coverage.



**Figure 2.3. Illustration of Parallel Mode scanning scheme. The grey area is the common SPIRE-PACS survey field what the observer specifies in HSpot. The scanning angle with respect the arrays' short axis is 42.4°. Red colour represents the SPIRE scanning path, blue colour is used for PACS.**

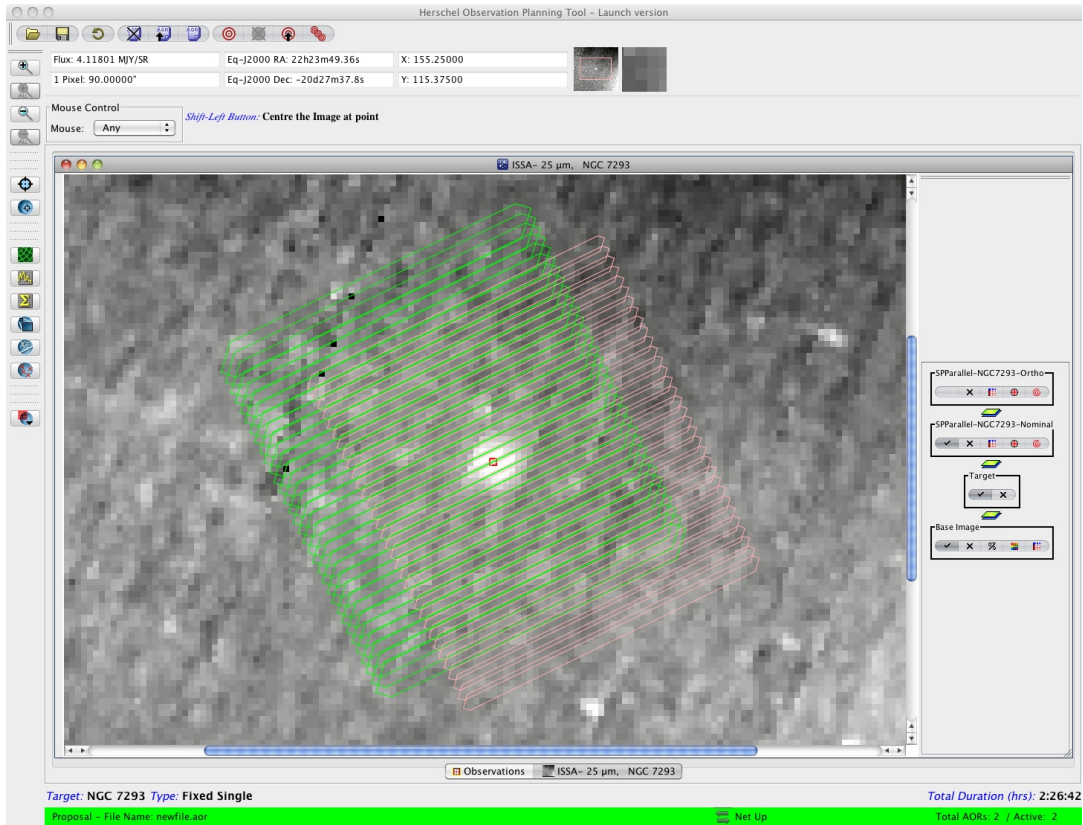
The centre of the common survey area is at the coordinates given by the target position, unless an offset along the axes Y or Z of the spacecraft coordinates is given. The map size along a scan leg can be specified by the map "Length" parameter. In perpendicular direction, the common survey size is defined by the "Height" parameter. In case the scan direction is set to "Orthogonal", then the observer has to change the "Length" and "Height" parameters and the spacecraft will perform an observation along -42.4° scan angle over the same survey area specified for the "Nominal" direction. The pairs of nominal and orthogonal AORs can be concatenated in HSpot (see further details in the [HSpot Users' Guide](#)).

An illustration of how a Parallel Mode AOR footprint is visualized in HSpot can be seen in Figure 2.4 and in Figure 2.5. Pink represents the PACS and green the SPIRE footprint: the observer requested common survey area is painted by both instruments. SPIRE and PACS coverage maps as taken from real observations is shown in Figure 2.6, Figure 2.7 and Figure 2.8.



**Tip**

It is recommended to concatenate Parallel Mode 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 as displayed in HSpot. NGC 7293 is imaged in "Nominal" scan direction with a coverage area of 54'x72'. A comparison between observer's requested area and real instrument coverages is presented in Figure 2.6.

Three optional parameters are available:

- "Bright Source Setting": enabling this setting (disabled by default), settings of SPIRE and PACS photometers will be optimized to observe bright sources, without saturating their dynamic range, but at the cost of sensibly increasing the instruments' noise. Depending on the science case, the observer might want to enable it for one or both instruments. Please refer to the [SPIRE Observers' Manual](#) and the [PACS Observers' Manual](#) for applicable flux thresholds.
- "Map centre offset": by default, the common SPIRE-PACS coverage is centered on the target coordinates. The observer has the option to apply an offset to the centre, given in spacecraft coordinates (Y,Z) in arcminutes.
- "Orientation": 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

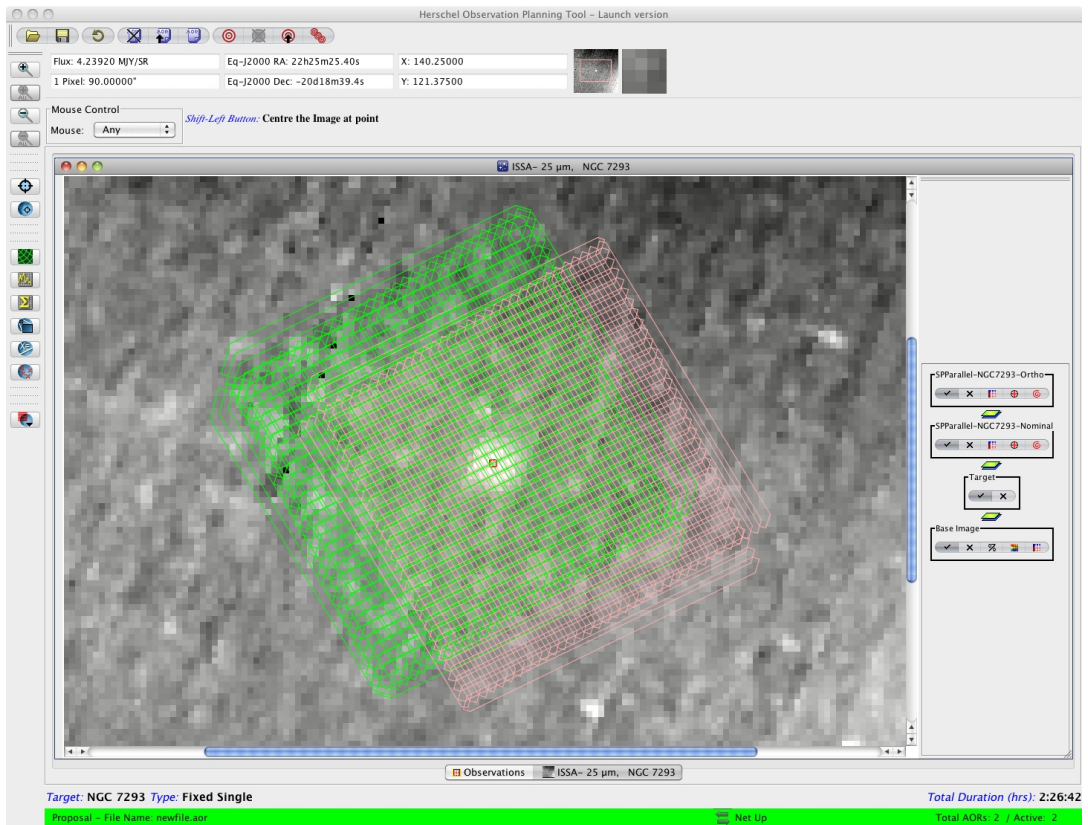
position angle", i.e. the angle from the celestial equatorial North to the scan line direction, counted positively East of North. This corresponds to the option "Array with Sky Constraint" in HSpot.

Setting a Map Orientation constraint means that your observation will not be able to be performed during certain periods, hence the 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 if the orientation constraint 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.

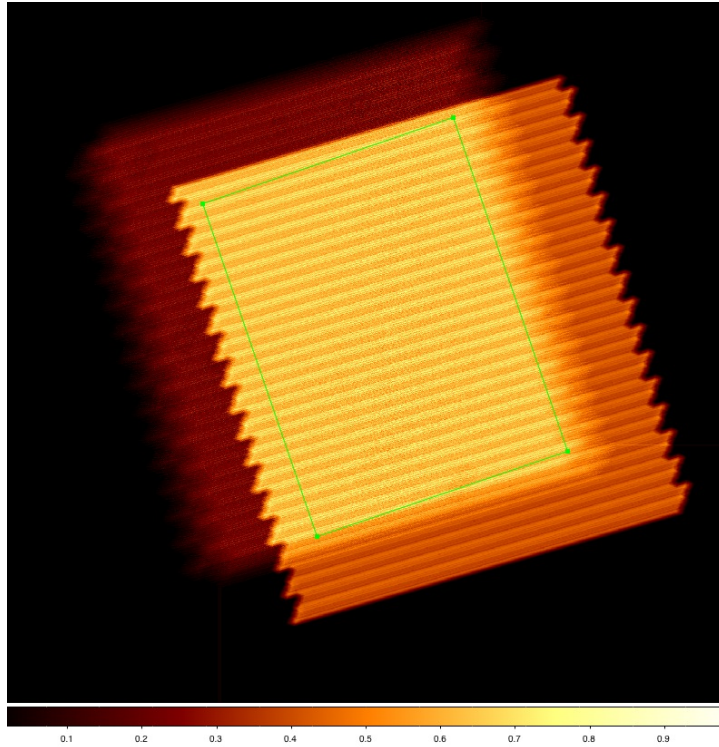


**Note**

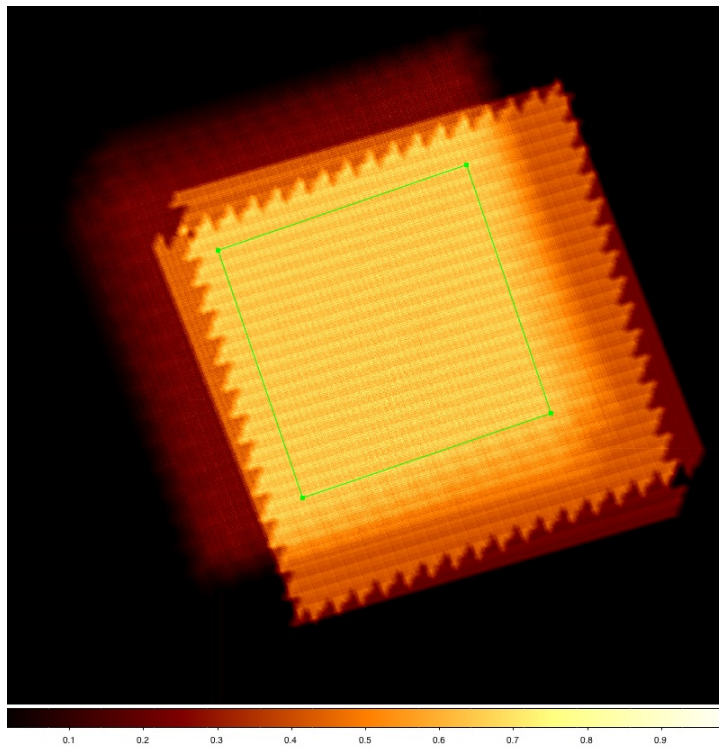
Setting constraints on when the observation can be performed make scheduling and the use of Herschel less efficient, hence the observer will be charged extra overheads to compensate (see Herschel Observatory Manual).



**Figure 2.5. Parallel Mode footprint image example as displayed in HSpot. NGC 7293 is imaged in "Nominal" plus "Orthogonal" scan directions. However, the "Length" and "Height" parameters are the same in the 2 AORs (instead of being inverted): the result is that the area covered by both instruments, in both directions, is only 54'x54' (see Figure 2.7).**



**Figure 2.6.** SPIRE (darker area, shift to left) and PACS coverage maps, normalized to 1, as obtained from observation of NGC 7293 in "Nominal" scan direction only. Overplotted in green is the original observer requested area of 54'x72'.



**Figure 2.7.** SPIRE (darker area, shift to left) and PACS coverage maps, normalized to 1, as obtained from observation of NGC 7293 in "Nominal" and "Orthogonal" scan directions. Overplotted in green is guaranteed area observed by both instruments, in both scanning direction. Since the "Length" and "Height" parameters were the same in the 2 AORs, this area corresponds to a square of 54'x54'.

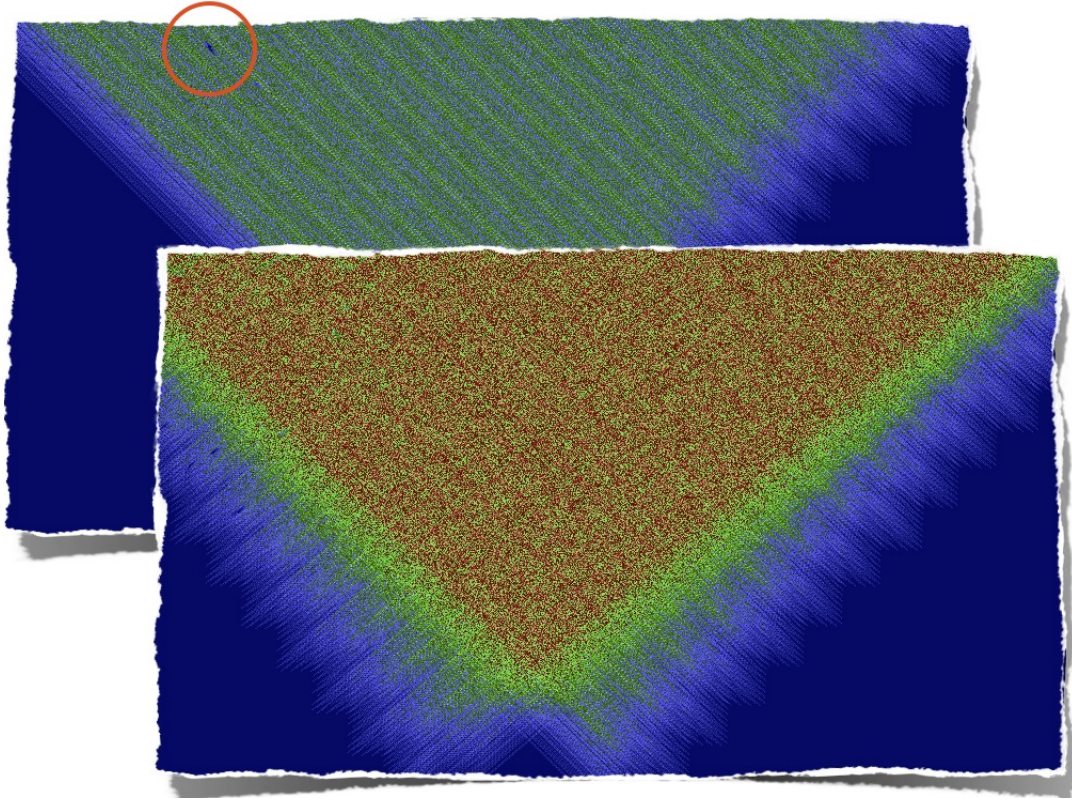


Figure 2.8. SPIRE coverage comparison between single-scan (figure behind) and cross-scans (figure in front) Parallel Mode observations. Note the better coverage of the latter, especially if some pixels have been masked out during data reduction (circled area).

Table 2.2. Observer 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 $\mu\text{m}$ or 85-130 $\mu\text{m}$ ).
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"/s) or slow mode (20"/s).
Length	Length of the common survey area parallel the scan direction in arcminutes: the maximum length is 1173'.
Height	Size of the common survey area in perpendicular direction in arcminutes: the maximum height is 232'.
Scan Direction	This parameter defines the scan angle along which the spacecraft builds up the scan legs. In "Nominal" direction the scan angle is $42.4^\circ$ and the scan

Parameter name	Signification and comments
	leg separation is 168", in "Orthogonal" direction the angle is set to -42.4° and the scan leg separation to 155".
Map centre offset Y	The offset of the map centre from the input target coordinates along the Y axis of the spacecraft coordinate system, in arcminutes.
Map centre offset Z	The offset of the map centre from the input target coordinates along the Z axis of the spacecraft coordinate system, in arcminutes.



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# Chapter 3. Changes to the document

Changes with respect to the version 1.1 of the SPIRE-PACS Parallel Mode Observers' Manual:

- latest SPIRE and PACS photometers in-flight sensitivities have been adopted in Table 2.1
- new scan leg separation for "Nominal" scanning direction: 168"
- new "Map centre offset" parameter available
- added Figure 2.6, Figure 2.7 and Figure 2.8; updated Figure 2.4 and Figure 2.5
- typos and other minor updates

Changes with respect to the version 1.0 of the SPIRE-PACS Parallel Mode Observers' Manual:

- latest SPIRE and PACS photometers predicted sensitivities have been adopted in Table 2.1
- added Figure 2.5 and updated Figure 2.4
- parameter limit "Height" has been changed to 232' in Table 2.2