

# PACS Wavelength Switching AOT release note

**Prepared by the PACS ICC**

**03 December 2009**

The following PACS spectroscopy AOT has now been released for scheduling of observations:

- Wavelength switching mode

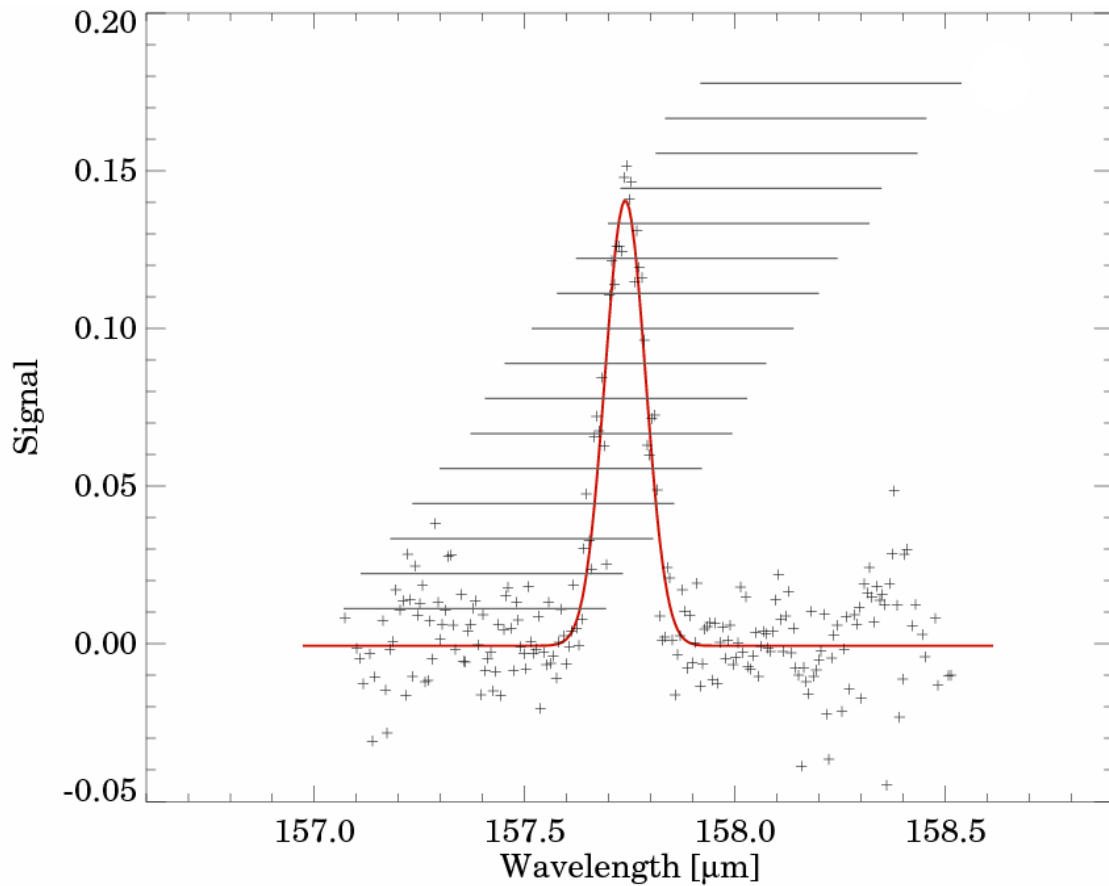
This mode has been released for the following pointing modes

- Raster mapping (n x m map with an off-source observation before and after map execution)

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

## **1 Technical implementation**

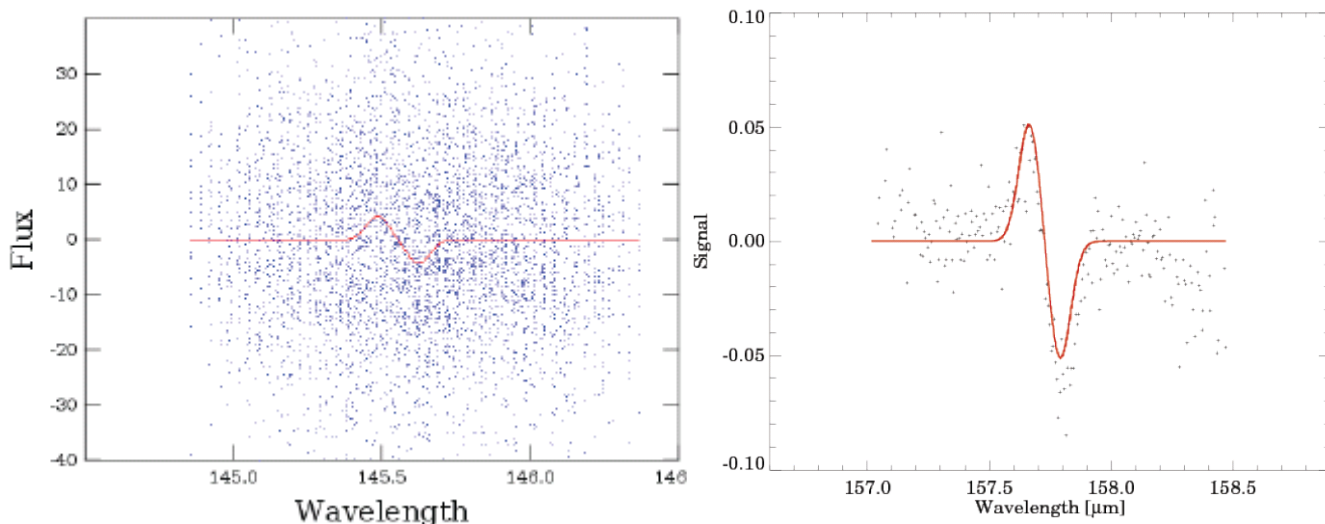
Changes have been made to the number of wavelength-switched pairs and the spacing between the wavelength shifts to optimize the observations for the detection of faint signals, especially in the presence of transient responsivity changes due to cosmic rays. The new scheme involved a AAABBBBAA pattern in which A represents a sample data-point taken at the initial reference wavelength, and B is at the wavelength-switched data-point (the leading “A” data point in this sequence is taken during the larger grating shift called Dither Step, see below). The difference in wavelength in this pattern is called the Switching Amplitude (SA). This cycle is repeated 20 times, moving the reference wavelength by a positive wavelength shift, called the Dithering Step (DS). After 20 cycles, the entire pattern is reversed, shifting to shorter wavelengths. This forms a series of upward and downward moving “scans” in which the target line is sampled. In order to correctly sample the lines, SA and the DS depend on the observing band and the grating order. These are: R1 (Red): SA= 1000 units ( $\sim 0.014\mu\text{m}$ ) DS = 240 units ( $\sim 0.033\mu\text{m}$ ) , B2B (Green): SA = 700 units ( $\sim 0.04\mu\text{m}$ ) DS = 188 units ( $\sim 0.01\mu\text{m}$ ) , B3 (Blue): SA = 600 units ( $\sim 0.024\mu\text{m}$ ) DS = 168 ( $\sim 0.007\mu\text{m}$ ). Figure 1 shows a representation of the upward scan component of a typical wavelength-switching observation.



*Figure 1: illustration of the wavelength range/line coverage each of the 16 spectral pixels of a module sees in the current implementation of 20 steps.*

## 2 Sensitivity

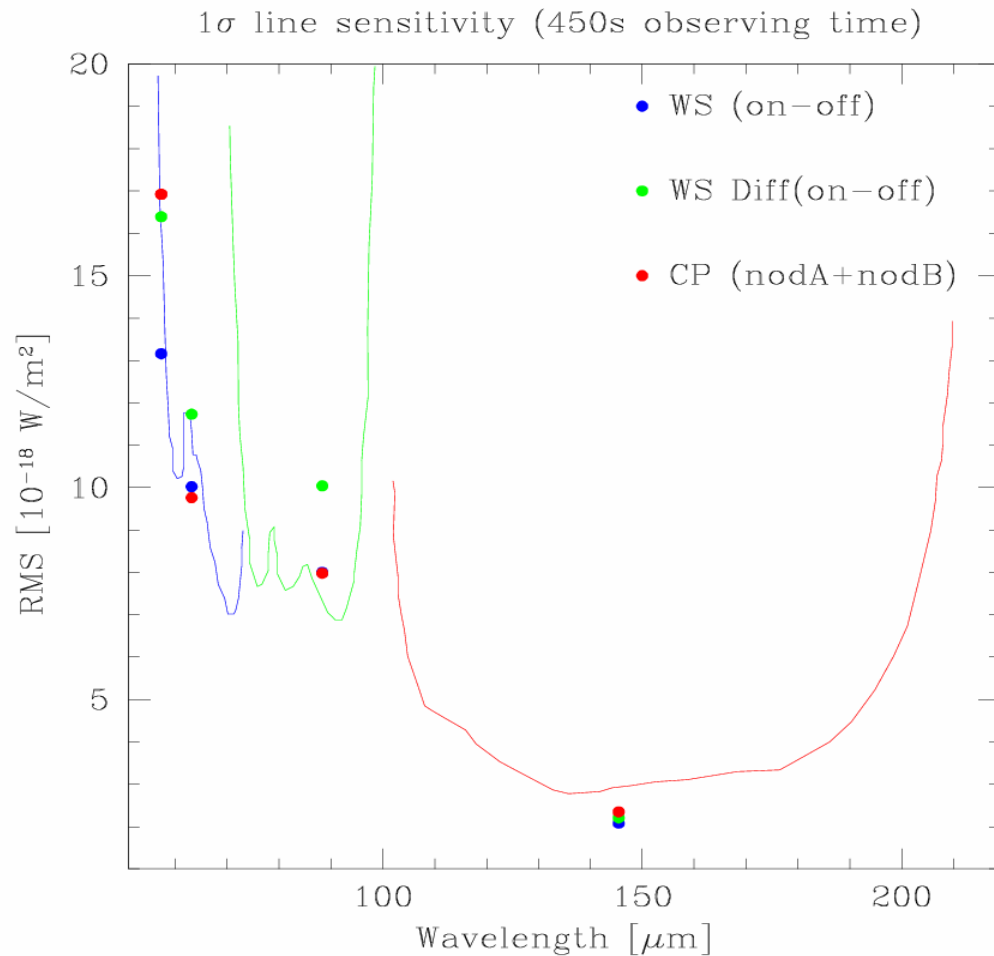
The wavelength switching data can be used to construct a spectrum in two different ways, and our measurements of sensitivity reflect these alternative methods. The first, which we call the ‘direct’ method, simply involves forming a spectrum out of all the available sampled fluxes and wavelengths—in a method akin to a scan map. This method does not take advantage of the wavelength-switching aspect of the observations. The second method, which we call the ‘differential’ spectrum, involves forming a spectrum of the difference between the ‘A’ points and the ‘B’ points in the wavelength-switched observations. The differential spectrum can be used to recover the line spectrum with model-fitting, and should be less sensitive to short-term detector responsivity changes or other drifts. The sensitivities calculated are shown in Figure 3 for the two methods (labelled WS ON-OFF and WS DIFF ON-OFF respectively).



**Figure 2:** two examples (for a faint and a strong line) of the reconstruction of emission line fluxes in the differential mode (by fitting a differential Gaussian).

These line sensitivities as a function of observing time have been verified in-orbit and are consistent with pre-launch predictions. They are also very similar to equivalent observations in chop/nod mode (for objects where this is possible). Note that the wavelength switching operation does not preserve continuum flux, although it can in some circumstances be recovered. There is currently a somewhat larger uncertainty in the red dark current values. Unlike chop-nod, where uncertainties in the dark are removed in the chopping differences, wavelength switching relies on a good estimate of the dark current per pixel before the relative spectral response function is applied. We expect that, as the mission proceeds, we will improve our estimates of the red dark current response, and this will allow a better (and probably less noisy) reduction of these data to be obtained.

We further note that in the measurements shown above, the differential method yields lower sensitivities than the direct method in the cases measured here in PV. However the difference between the two cases is better than the expected  $\text{SQRT}(2)$ , indicating that some improvement is gained by differencing the spectrum. Although, in the current analysis, the difference spectrum does not do better than the direct approach, we caution that in some circumstances this may not always be the case, and the observing strategy always allows this difference spectrum to be calculated if needed. We will provide both kinds of spectral cube products in the wavelength-switching pipeline.

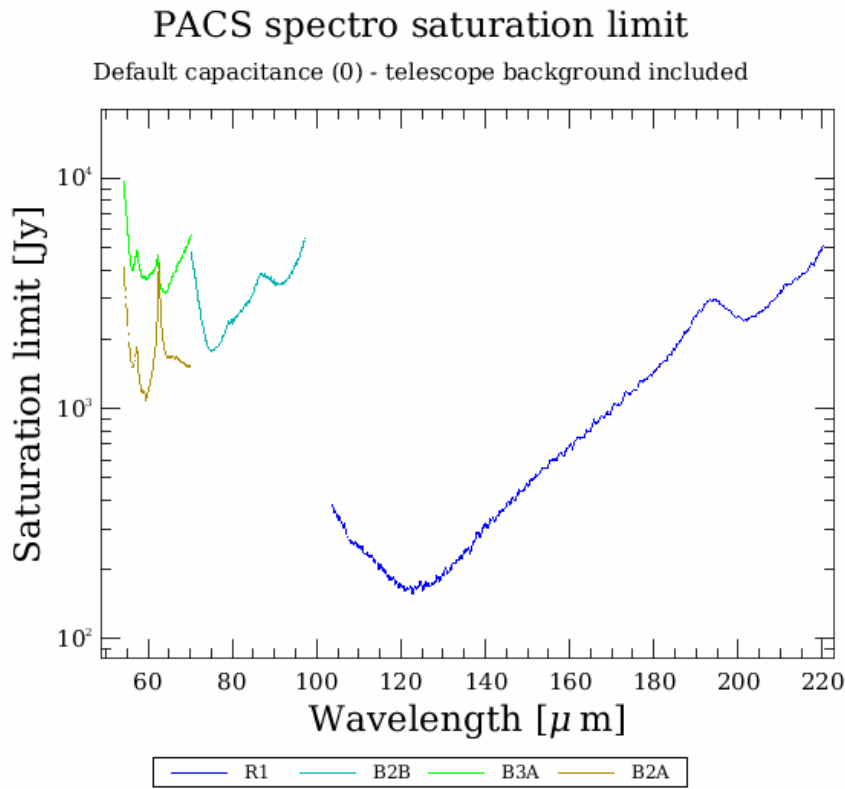


**Figure 3:** comparison of pre-launch sensitivity predictions as documented in the PACS observers manual (solid line) to noise determinations for wavelength switching and equivalent chop-nod observations for a total observation time (including off-observations) of 450 seconds.

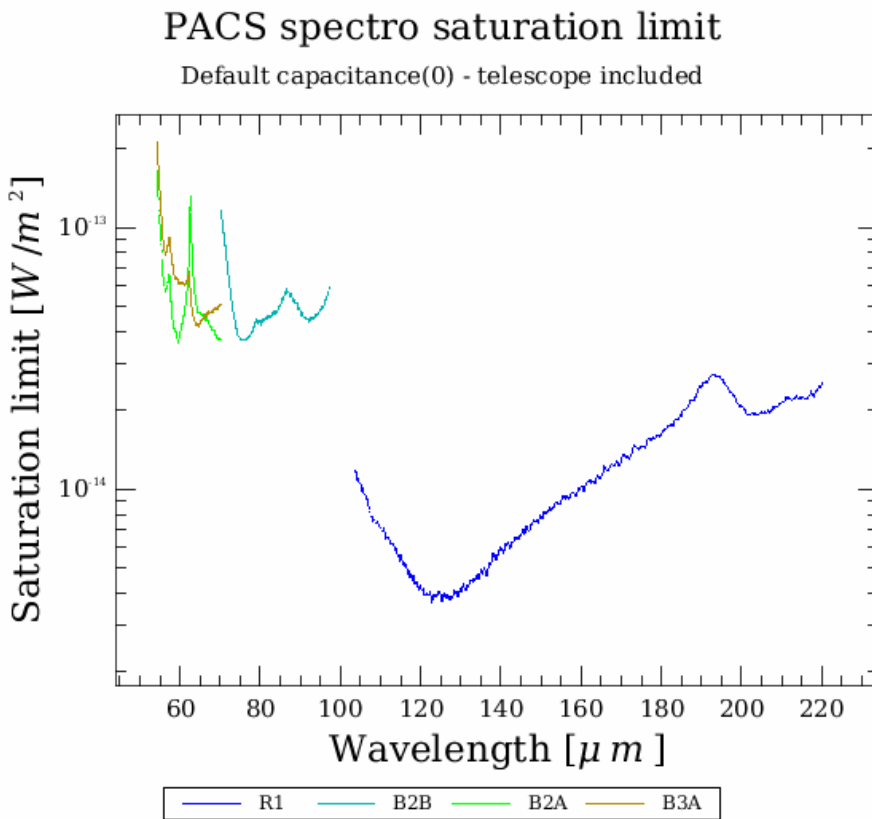
### 3 Saturation limits

The automatic selection of integrating capacitance based on estimated continuum and line fluxes in the uplink logic is still being implemented based on in-orbit measurements of the telescope background and detector responses. Until this is implemented, only observations within the saturation limits of the default, smallest capacitance are to be scheduled.

Figure 4a shows the saturation limit in Jansky for the default integration capacitance. This is the limit for continuum and peak line flux together. Figure 4b shows the saturation limits for unresolved lines on a zero continuum. Both figures should allow to judge if the observation can be executed with the default integration capacitance.



**Figure 4a:** Saturation for the default integrating capacitor



**Figure 4b:** Saturation limits for the smallest capacitance for unresolved lines

## 4 Spatial and Spectral resolution

The spatial and spectral resolving power have both been verified in-orbit, and are consistent with the values given in the observers manual. No significant differences have been found between the line-widths of lines recovered in the wavelength-switching mode as compared with standard line-scan mode, although we are continuing to evaluate this to obtain more statistics.

## 5 Pointing

The telescope can centre the intended target coordinates to about  $\sim 2$  arcseconds-or a fraction of a spatial pixel. Since in wavelength-switching mode the chopper is not moved (offsets are done in sky-coordinates by moving the telescope) there are no chopper-dependent distortion corrections to be applied.

## 6 Mapping

The PACS spectrometer spatial pixels ("spaxels") of  $\sim 9.4'' \times 9.4''$  size are undersampling the diffraction beam of the Herschel telescope. With several observations (the number depending on wavelength), offset by fractional pixel size steps, the full spatial information can be retrieved. The raster pointing mode is used to generate a suitable set of pointings. Depending on the purpose of the raster map, different raster step sizes are recommended.

Note that these mapping strategies do not depend on whether the signal modulation is done with the grating (i.e. wavelength switching) or with the chopper. Therefore the recommendations given here are the same as for the nominal (chop/nod) line spectroscopy case.

### 6.1 Tiling the sky

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

### 6.2 Nyquist sampling map of extended objects

For extended objects, mapping with oversampling, i.e. with step size smaller than one spaxel, may be very time consuming. Therefore we have tested a mapping strategy with step sizes larger than one spaxel, but such that the beam is nyquist sampled. Since the PACS Spectrometer projected pixels in the sky are not square, the best recommended step sizes are not equal in Y and Z dimension, (YZ being the spacecraft axes where Y corresponds to the PACS chopping direction) and of course the optimal size changes with the beam size at different wavelengths.

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

BLUE:

raster step size in z direction =  $16.0''$

raster step size in y direction =  $14.5''$

RED:

raster step size in z direction =  $24.0''$

raster step size in y direction =  $22.0''$

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

### 6.3 Full PACS spatial resolution Mapping of compact objects

In order to map the sky at full PACS spatial resolution, step sizes smaller than a spaxel have to be used. Since this increases the observing time, this mode is strongly suggested to be used only for mapping point-like or almost point-like objects, which is not normally the case for objects observed in wavelength switch mode.

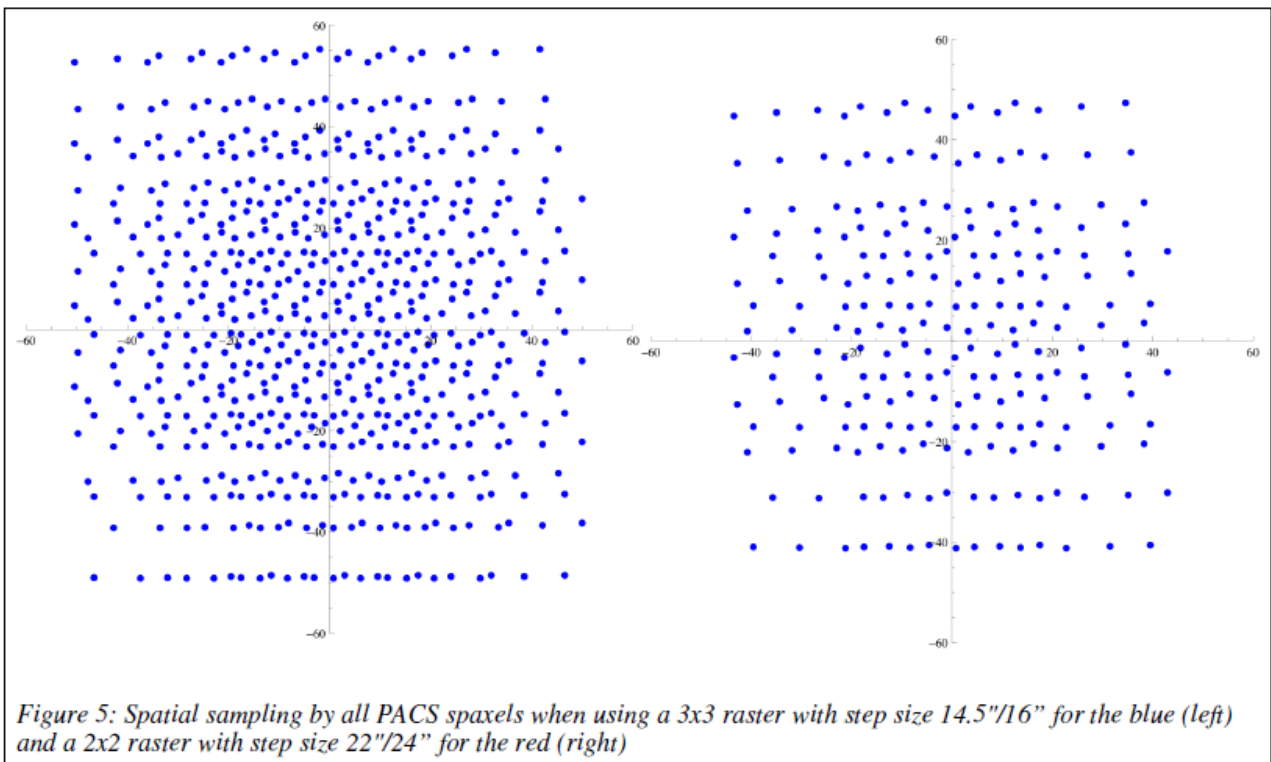
In order to recover the best PACS resolution we recommend the following minimum number of raster positions AND maximum step sizes:

BLUE:

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

RED:

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



## 7 Calibration and pipeline status

A development version of the 2.0 track of the PACS spectrometer pipeline is required to perform wavelength-switching reduction, and currently (at the time of this release) is still undergoing final testing. However, we expect that in the timeframe of the first WS SDP observation we will have a fully-functional WS pipeline available for users. This will likely be in the mid-to-late-December 2009 period.

Important sky calibration sources for the wavelength, flux and spatial calibration only became visible in the course of October. Therefore the current versions of the pipeline are still based on ground calibration values. The wavelength calibration accuracy is well within the uncertainties in wavelength imposed by the dependence on source position in the slit. The ground flux calibration is estimated to be valid for in-orbit conditions to within 50%. The spatial calibration applied in the pipeline is accurate to  $\sim 2$  arcseconds, partly due to the limited accuracy of the early implementation

of the aberration correction algorithm, partly due to alignment differences of the instrument-level ground test setup versus the integrated instrument-telescope system.

Updates to these three calibration aspects are well under way, and are expected to be incorporated into the version suitable for wavelength-switching analysis. The HSC will provide stable beta-versions of the 2.0 track to the observers as the updates to the calibration are validated. We expect documentation describing the wavelength switching pipeline in the January 2010 timeframe. The observing mode and its data reduction will be demoed at the December DP workshop at ESAC, and at the January DP workshop at NHSC.

## **8 Recommendations for HSPOT AOR updates**

With the current implementation, there are no major recommended changes to the previous strategy. The time interval between two off-source observations (currently at the beginning and end of a raster) has only been evaluated on the basis of short PV observations. Although these observations do not seem to indicate the need for more frequent off-source measurements, the PACS team will monitor this in future observations, and may recommend changes if they are necessary.

As explained in Chapter 6 raster map step sizes have to be expressed in spacecraft coordinates. The necessary changes to HSPOT have been implemented by now.

The atomic observing time in wavelength switching mode has increased by 10% including instrument and observing overheads (180 sec). This is because the integration time per spectral resolution element has been increased from 33 seconds to 40 seconds in the new logic. The shortest duration of 385 seconds has increased to 420 seconds.

Observers need to revise the repetition factor, but only if

```

old_repetition >= 5 then new_repetition = old_repetition - 1
otherwise
new_repetition = old_repetition.
```