PACS Release Note

Unchopped line scan

and

Unchopped Range Scan/SED Mode
(Referred to generically as Unchopped Mode)

Prepared by the PACS ICC
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1.0 Introduction

As a result of tests performed in PV Phase, we have decided to release two new AOTs which use the spectrometer in a second generation observing mode called Unchopped Grating Scan. The first, Unchopped Line Scan, replaces the previously released Wavelength-switching mode (which will no longer be used), and secondly we release a new Unchopped Range Scan AOT, which includes a fast SED mode. Dedicated observations have demonstrated that both the Unchopped Line Scan mode and the Unchopped Range-scan/SED modes work well for reproducing line shapes and line fluxes when compared with similar observations performed in chop-nod, over a wide range of line fluxes. However, we caution that this mode currently does not reproduce very well the continuum for fainter sources (anything less than 20 Jy) and this mode is not currently recommended for continuum measurement in SED or large range-scan mode where the absolute continuum level is central to the science objectives. However, for line measurements, the mode offers an attractive alternative to chop-nod in cases where the target source is either too large for chopping, or lies within a complex field.

2.0 Technical Implementation of the Mode

2.1 Unchopped Line Scan

When PACS Line Spectroscopy is chosen in HSpot, the user can select lines in much the same way as in Chop-Nod Line spectroscopy, except in this case the telescope chopper is always positioned at the zero position and the grating is scanned twice up and down on the target, and then on a user-defined "off" position that can be up to two degrees away from the target. The step size of the grating movement is identical to that used in the chop-nod scan, but in new mode, the grating is stepped over a wider wavelength range (75 steps compared with 43 in chop-nod). However, because less time is spent at each grating position, the overall minimum time taken to perform the shortest possible pointed observation is very similar to that of chop-nod (~ 580-590s with overheads--see below). More useful information can also be found in the PACS User Manual (**http://herschel.esac.esa.int/Docs/PACS/html/ch06.html#tab:linescan_scan_params**), although we caution that this release document updates some aspects of the PACS UM.

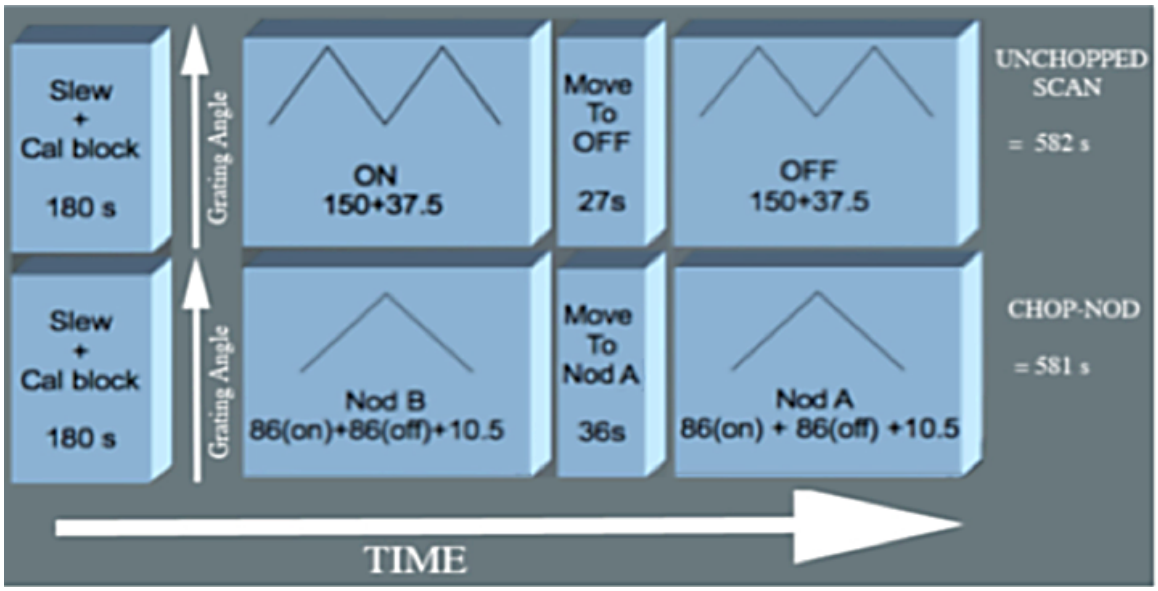

Figure 1 Comparison of one repetition in pointed Unchopped line-scan mode compared with a similar Chop-Nod observation. The duration of the execution is the same.

Figure 1 shows a comparison of a single line repetition of the new Unchopped line-scan Mode (top) compared with a single line repetition for Chop-Nod line-scan (bottom). In Unchopped mode, the up/down grating scan have been made much faster than in the chopped mode, and every line repetition requested by the observer is doubled internally by PACS. On every grating position, four integration ramps are taken. Each integration lasts 1/8 s, resulting in a grating scan which is faster than the one in chopping mode. The scan also extends over a wider wavelength range than in the case of chopped-nod (75 steps compared with 43). After an initial calibration block lasting 180s (performed while the telescope is slewing to the target) two up and down scans of the grating are performed on source (150s plus 37.5s overhead) followed by a slew to the user-specified "off" position in which the process is repeated. The minimum execution time is thus approximately 580s (in practice the time may be longer due to differences in slew times etc). This is comparable to an equivalent observation in Chop-Nod (lower part of Fig. 1).
The example above is for a single pointed observation. If a map is selected, the "off" observation can be forced to execute after a certain number of raster steps. The optimal choice of "off" frequency in this case will be discussed below is a separate section.

Figure 2 shows the range of wavelengths covered by each spectral pixel during the course of a scan. Every spectral pixel of the detector "sees" the target line pass over it at some point during the scan.

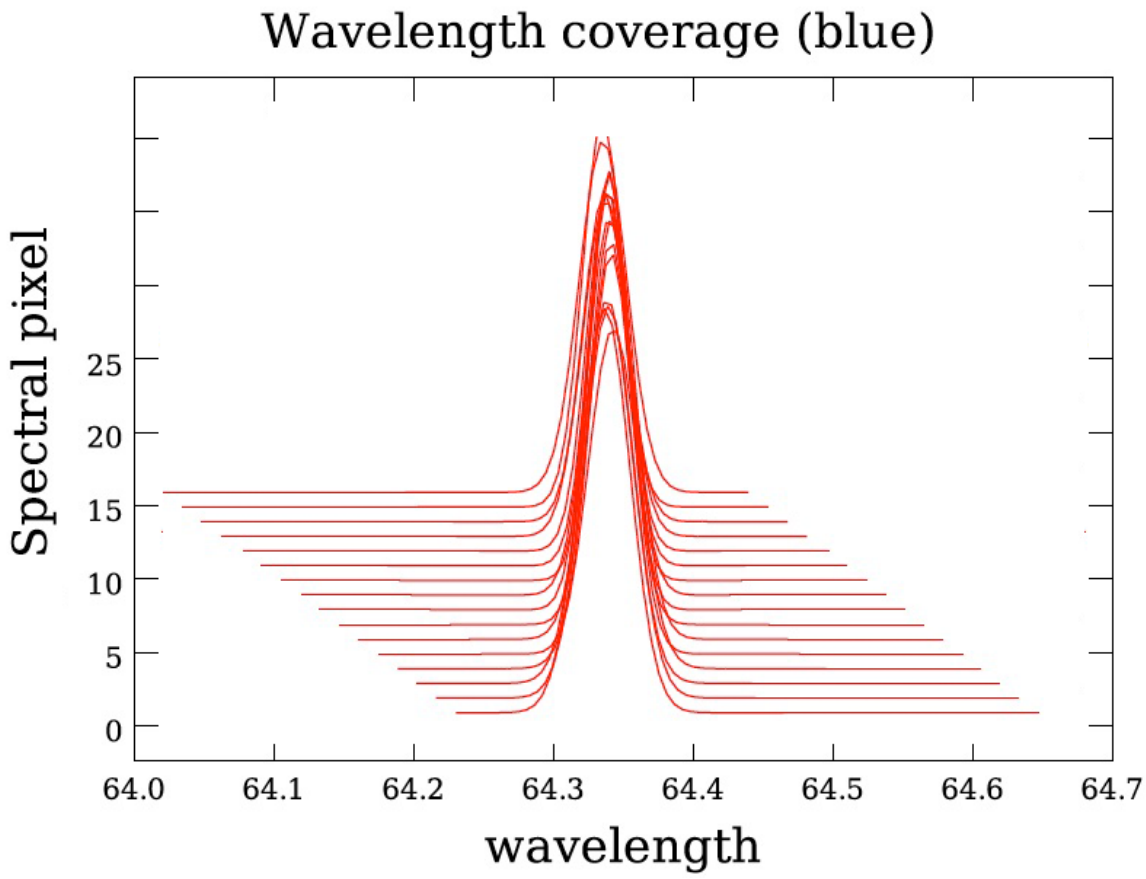

Figure 2: The spectral coverage of a bright line as seen by each of the 16 spectral pixels in the central spaxel of the blue detector array. The plot shows on-flight data for a bright line observed during tests. Similar coverage is provided in the red.

2.2 Unchopped Range Scan

IMPORTANT NOTE: Unlike the Line Scan mode, Range/SED scans does not allow for a specific "off" position to be specified within the AOR. Rather, a SEPARATE AOR needs to be created to perform an identical observation "off" the source. It is mandatory, based on our experience with in-flight testing, that the "off" have the same duration as the "on" source observation. The "off" observation would need to be added as a grouping timing constraint (e. g. concatenation) when the AORs are created in HSpot.

When PACS Range Spectroscopy AOT is selected in HSpot, the user has several options for observing:

- There are three SED options which provide fast (Nyquist sampled) coverage of the available wavelength coverage. If a full SED is required the observer can choose options B2B +Long R1 combined with B3A + Long R1 to take full advantage of the full range of orders. Alternatively in the blue, instead of B3A + Long R1, the user could select B2B + Short R1 to provide more blue sensitivity by exploiting the extended second order B2B (See PACS User Manual for more details). A simple recipe for a standard SED mode would be as follows: e. g. AOR 1 = B2B+Long R1 (ON SOURCE), AOR 2 = B2B+Long R1 (OFF SOURCE), AOR 3 = B3A + Long R1 (ON SOURCE), B3A + Long R1 (OFF Source). This pattern will take approximately one hour to complete the full SED. The four AORs should then be grouped together as a Tools>Group Follow-on Constraints> and then Select "Add Concatenation" —then drop the AORs into the pop-up window to create the sequence.

- There are three range-scan options which allow the user a bit more flexibility in making a broad measurement. Here the user can add blue and red edges to scans within the same three broad-bands as before. Unlike the SED mode, the user can choose deep scans which are performed with the same sampling as a normal line scan. These can be very expensive in time, so care should be taken in performing high-density sampling for large spectral regions. By clicking on the "add range" button, the user can add line strength information which will be used by the time estimator to estimate the rms noise.

In the Range Spectroscopy Unchopped Mode the grating scan strategy is very similar to the implementation as described above for the Line Spectroscopy Unchopped Mode. In Unchopped mode, the up/down grating scan have been made much faster than in the chopped mode, and every range repetition requested by the observer is doubled internally by PACS, i.e. each repetition the observer defines in the Range Editor table or in the "Nodding, grating scan or mapping cycles" field translates into two internal repetitions. On every grating position, four integration ramps are taken. Each integration lasts 1/8 s, resulting in a grating scan four times faster than the one in chopping mode. (In chopped mode for every grating position PACS takes 16 ramps within two chopper cycles).

Taking the example of an "SED B2B" scan, in both chopped- and unchopped observing modes the grating visits 262 steps with step size 2400 units. Such a scan (up- and down) takes 1048 seconds in the chopped mode for both ON- and OFF fields without overheads (262*1/8*16 for 2 nod positions gives 1048). In unchopped mode, a single repetition scan takes 524 seconds ON (or OFF) source, two repetitions integrates 1048 seconds and so on.

A concatenated ON-OFF pair of "SED B2B" unchopped AORs with range repetition = 2 takes 1048 (ON) + 1048 (OFF) seconds to execute, therefore this configuration has exactly the same sky time (2096 s) as a chopped "SED B2B" observation of a single repetition. Note, for very bright sources applying a single range repetition, the unchopped mode integrates half the time (including ON+OFF) comparing to the shortest chopped version. However, we strongly discourage users from adopting this method of observing for purely efficiency reasons if chopping is an option.

2.3 Unchopped Line- and Range Scan AOTs in HSpot

Note that HSpot version 5.1 provides both pointed- and mapping options of the unchopped grating scan mode, and the impact of main AOR parameters on time estimation has been described in the above two sections. However, although the time estimation (total observing time as well as on/off block durations and overheads) is correctly calculated and summarized in the "Time estimator messages" window, the line S/N and continuum rms estimation is not correct due to a software bug (which will be corrected in the next HSpot version).

As a rule of thumb, you can use the line S/N and rms estimation from the chopped mode in HSpot as a guide to what is expected in the unchopped mode. As a work-around, you can adjust the total integration time (called "SRC+REF" in the time estimation message) in the upchopped mode until it agrees with the same time in an equivalent chopped AOR—and then use the chopped line S/N and rms as a guide. In practice, for Line Spectroscopy, similar repetition factors yield similar rms values in the two modes, whereas, as described earlier, for range spectroscopy 2 repetitions would be needed in unchopped mode to reach the same depth as in chopped mode.

3.0 When to use Unchopped Mode?

It is recommended by the PACS ICC that this mode be only used when chopping is not practical. The unchopped grating scan is an alternative to the chopping/nodding mode if the maximum chopper-throw of 6 arcminutes does not take you off the target. For instance, this could happen in crowded-fields, or for

spectral line mapping of extended objects with diameters larger than 5' respectively. More details about the observing mode can be found in Section 6.1.8 of the PACS Observer's Manual (http://herschel.esac.esa.int/Docs/PACS/html/ch06.html#sec-unchopped-grating-scan). These details will not be repeated here.

Based on experiments done in-orbit, we have found that reproduction of the absolute value of the continuum in this mode is not reliable for faint sources and we do not recommend using this mode to measure the continuum if the continuum source is less than ~20Jy at the desired wavelength. Unlike Chop-Nod observations, which can monitor short term variations in responsivity by rapid comparison with chopped "off" positions rapidly, Unchopped mode observations rely on (1) high redundancy of spectral coverage by performing a large number of fast up/down grating scans, and (2) monitoring responsivity changes by fitting drifts in individual detectors with time.

If the continuum is brighter than approximately 20 Jy we have found from tests that the use of the "off" observation will provide a final spectrum that is well matched to a chop-nod equivalent spectrum (such observations are likely to be uncertain in absolute terms to 30%, but the shape of the continuum is expected to be reliable. The absolute levels could be further improved if observations of the same source were made with the PACS photometer.

For faint sources (< 10-20 Jy), the continuum level of the source falls below ~10% of the telescope background, therefore an accurate continuum reconstruction (both magnitude and shape) would require an accuracy of few percent (1-2%) of the background flux, whereas the current calibration is only good to several tens of a percent. Under these circumstances we do not recommend using the mode to reconstruct the shape and magnitude of the continuum. However, as we will show below, the line fluxes and line shapes are quite reliably reproduced in this mode and the shape of the continuum over small segments is also quite well reproduced. The above comments apply only to the large-scale shape of the continuum and its magnitude.

4.0 Sensitivity of the Mode Compared with Chop-Nod

4.1 Line-Scan Mode

The sensitivity of an observation performed in the Unchopped line-scan mode is quite similar to that obtained in chop-nod when the time spent on source is taken into account. This conclusion is based on actual observations of several galaxies in which bright lines were observed both in chop-nod and in unchopped mode. Both the line shape and the strength of the line (when differences in the calibration procedures are taken into account) are very similar. Figure 3 shows the observation of a line in the red spectrometer observed in both Chop-nod and Unchopped mode. The unchopped observations where made in a sequence, ON1, OFF, ON2 and the result of ON1-OFF, and ON2-OFF are compared with a chop-nod observation. Except for differences in the continuum level, the line is well reproduced in both cases. Note that in this example both unchopped observations over-estimate the continuum by 30% compared with the chopped case, and are also different by 10% between each of ON1 and ON2 spectra. This continuum uncertainty has been discussed previously. Observers should not use this mode to measure the continuum. Figure 4 should another example, this time in the blue spectrometer where the differences between the chopped and unchopped levels are not so large. In this example, an absorption line was detected against the continuum. We caution that Equivalent Widths, which rely on a good measurement of both the line to

continuum ratio are not reliable in Unchopped Mode unless the source continuum is very bright (> 20 Jy).

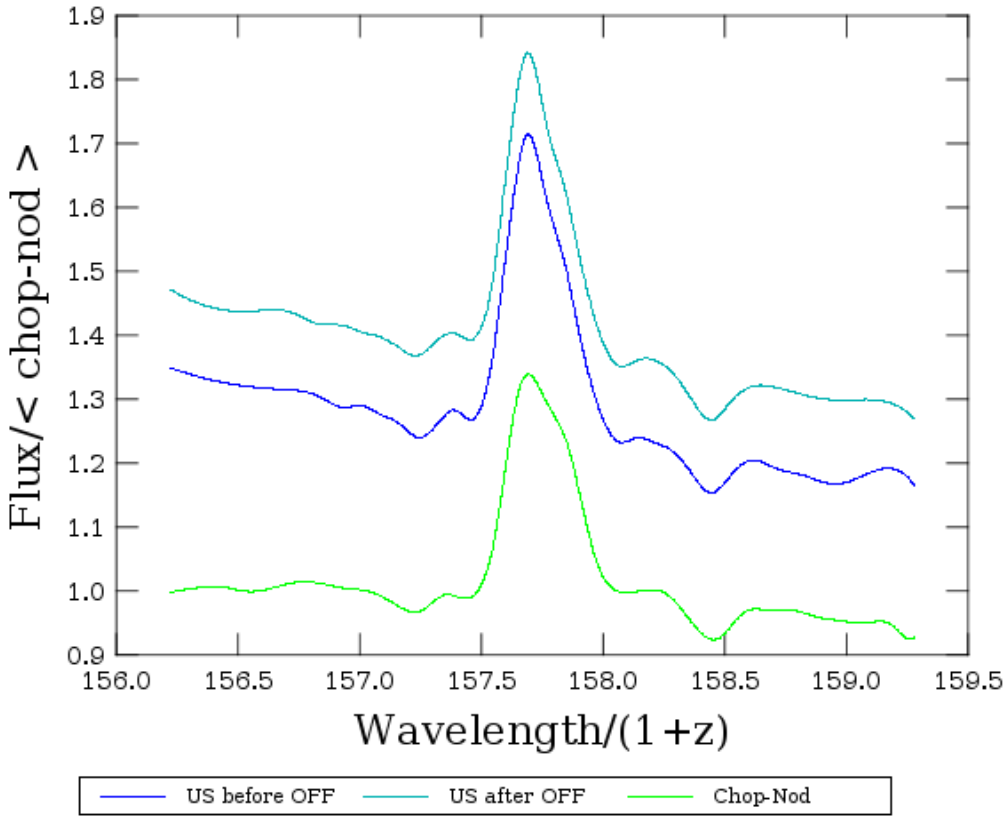

Fig. 3 A comparison of same red emission line source observed with Unchopped Mode and a Chop/Nod observation. The purple and blue spectra are the unchopped spectrum taken before and after the subtraction of the same "off" observations (obtained mid-way between the "on"s) and show a variation between each other in the continuum of the order of 10%. The Green spectrum shows the same source observed in chop-nod mode where the continuum is much more accurately measured, and is lower than the Unchopped Mode by approximately 30%. Note that the line itself is well reproduced in both flux and line shape. The systematically larger amplitude of the line-signal seen in the Unchopped Mode compared with Chop/Nod (roughly 10%) is a known artifact of the way the line is calibrated in this example, using methods designed for chop-nod calibration. Future calibration tables designed for the Unchopped Mode will remove this scaling difference.

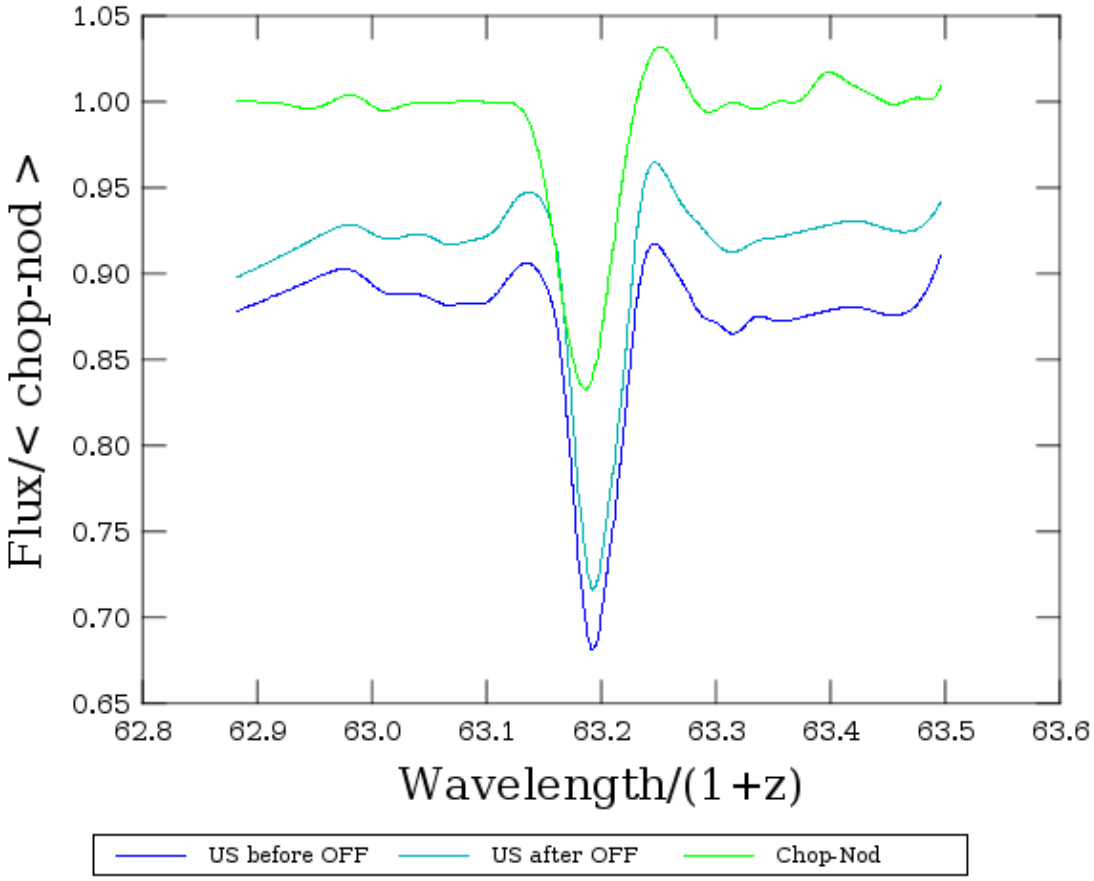

Fig. 4 Example of comparison of a Blue absorption-line source observed with Unchopped Mode compared with a Chop/Nod observation. The color scheme is the same as for the previous plot. In this example, the absolute level of the continuum for the unchopped source (purple and blue) is 10% lower than that measured in the chop-nod measurements (green). Again the line itself is well reproduced in the unchopped mode (the slight shift in the wavelength of the line in chopped mode may have something to do with slightly different pointing between the two set of observations which can lead to small shifts if the source is not centered on the slit). We note that the integration time was a factor of two longer in the case of the unchopped observations compared with the chopped mode in this example.

Figure 5 shows a comparison between the measured rms line uncertainty in Chop-nod and Unchopped observations scaled to a 450s integration time (similar to the plots shown for other modes in the PACS Observer Manual). Although so far we only have a few lines measured in this mode, the results agree favorably with respect to HSpot predictions.

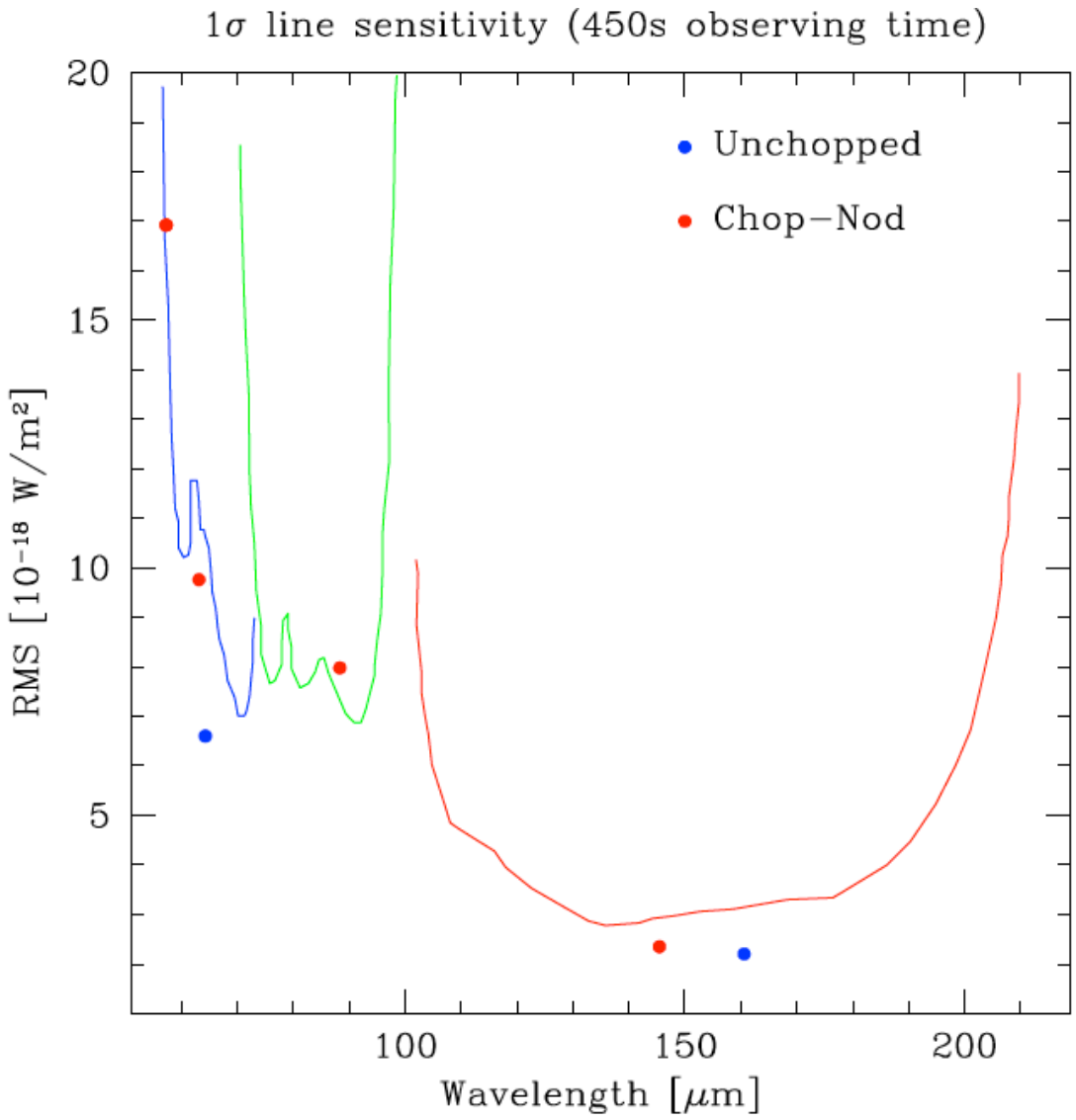

Figure 5. The line rms uncertainty for chop-nod and unchopped observations compared with HSpot predictions for an equivalent 450s total on-source integration. The unchopped mode performs well compared with expectations.

4.2 Range Scan Mode

A comparison between range-scans in Chop-Nod and Unchopped modes also shows that the Unchopped mode reproduces the spectral features well. Figure 6 and 7 show a comparison over broad as well as narrow ranges between range scans performed in Chop-nod and Unchopped mode in both the blue and the red spectrometer. As can be seen from the figures, the unchopped mode compares very well to the chopped mode. The rms noise obtained in the unchopped mode, when an "off" of equal duration is used, produces very similar rms noise values to equivalent chop-nod observations and both lie close to the HSpot predictions (see Fig. 8). Unchopped test observations have been executed in an ON1-OFF1-ON2-OFF2 sequence of observing blocks, the total integration time in such a sequence is twice as long as the corresponding chopped observation. The reproducibility of subsequent ON- and OFF pairs (ON1/ON2 and OFF1/OFF2) is better than 6% average over the observed ranges on a maximum of 2 hours timescale (this would be the maximum recommended interval between "on" and "off" sequences). Except for differences

in the continuum level, line shapes and fluxes are well reproduced in the test cases. Note that in this example both unchopped observations over-estimate the continuum by a maximum of 30% compared with the chopped case, This continuum uncertainty has been discussed previously.

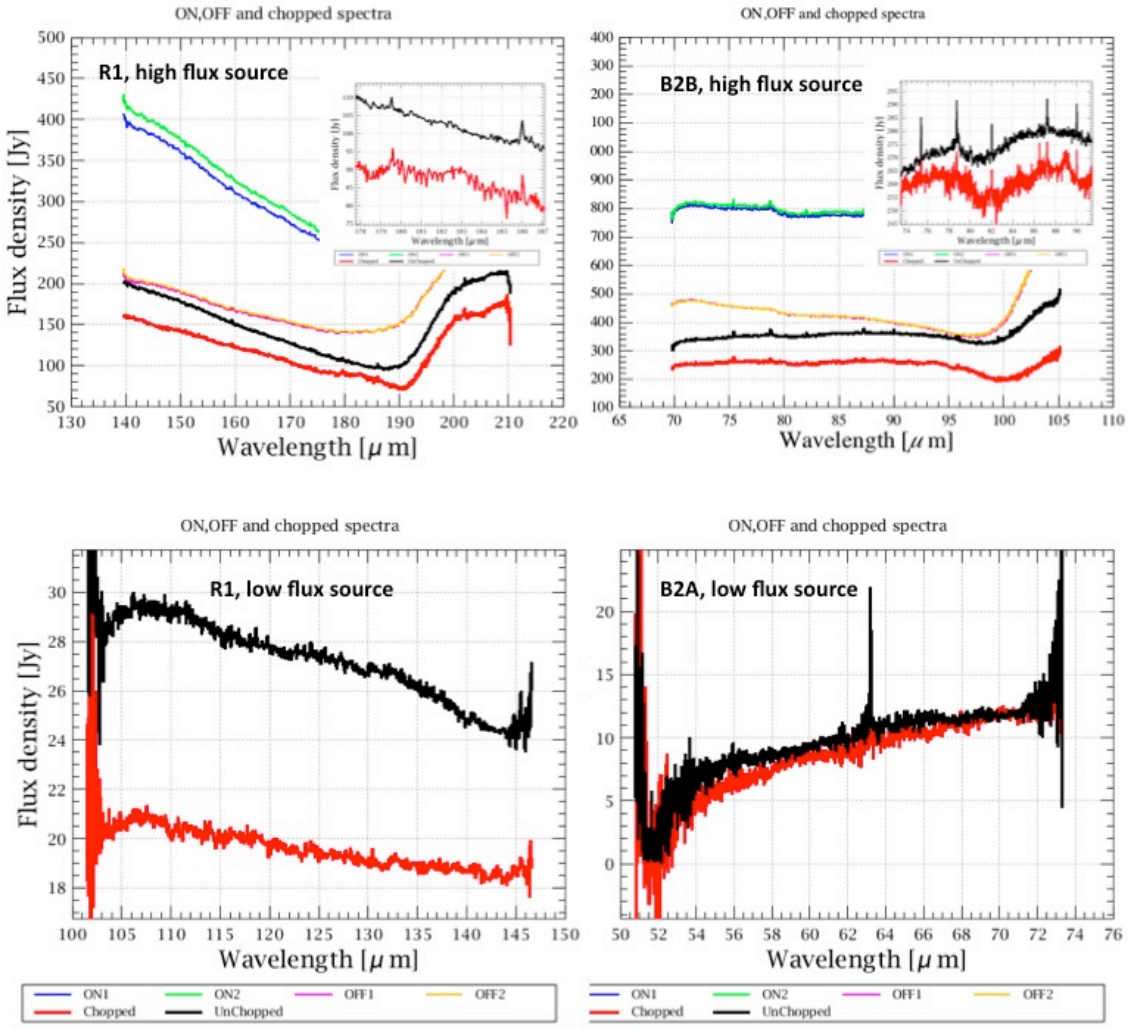

Fig. 6 Examples of bright- and faint source spectra observed with Unchopped Mode and a Chop/Nod SED observations. The black curves are the unchopped spectra, the red curves represent the chopped observations where the continuum is much more accurately measured, and is lower than the Unchopped Mode by approximately 30%. Blue and green show the ON1 and ON2 blocks, yellow and purple show the OFF1 and OFF2 blocks of the unchopped observations. In these test cases the total integration time in unchopped mode is twice as long as in the chopped mode, the black curve combines all four blocks: ON1,OFF1 and ON2,OFF2. The variation in the continuum between each of the ON1/ON2 and OFF1/OFF2 blocks is in the order of 6% on a 2 hours timescale. Note that continuum shapes are well preserved in both modes. The systematically higher continuum seen in the Unchopped Mode compared with Chop/Nod is a known artifact of the way the flux is calibrated in this example, using methods designed for chop-nod calibration. (A zoom on the normalized spectrum of the OI line in the lower right figure is shown in Fig .9)

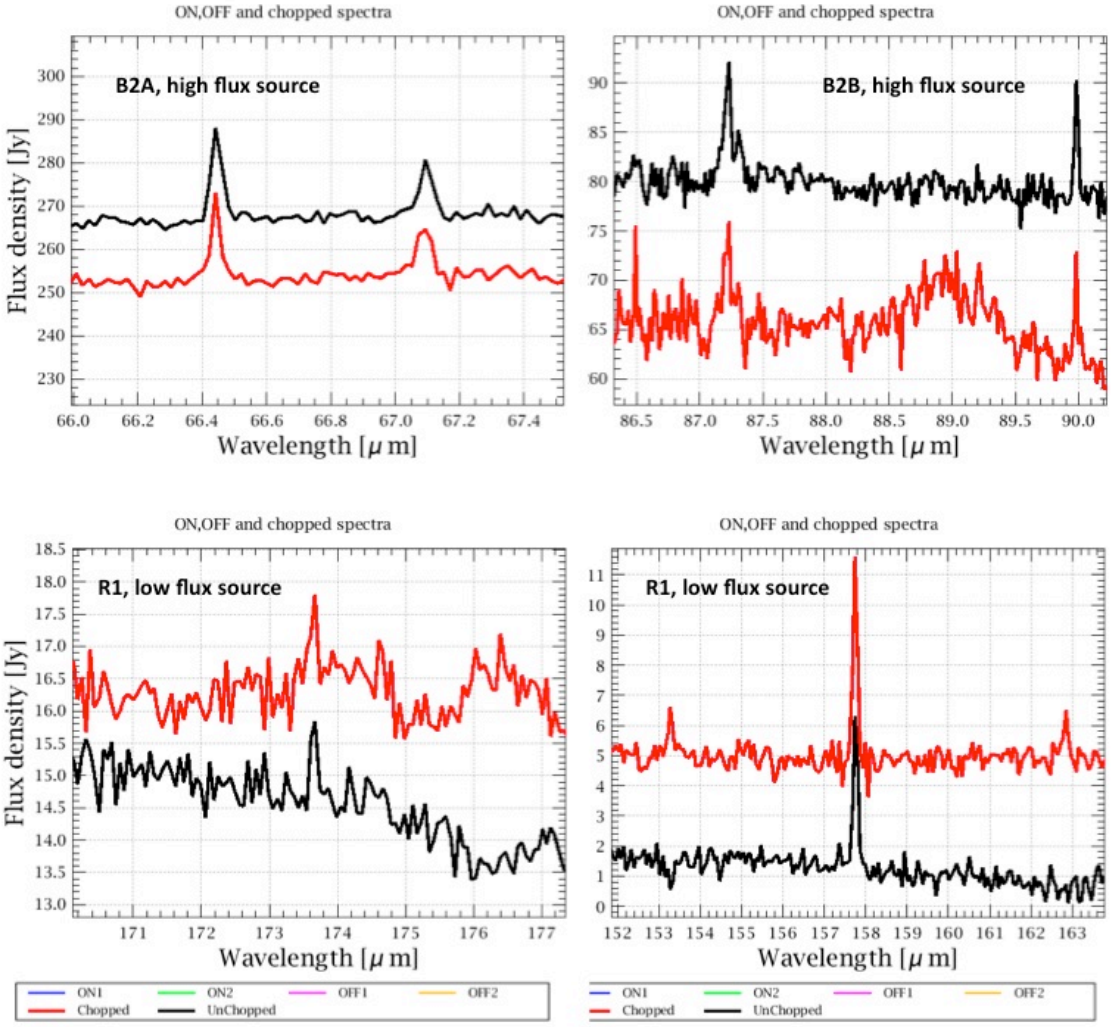

Fig. 7 Similar to Fig. 6, examples of bright- and faint source spectra observed with Unchopped Mode and a Chop/Nod SED observations are shown, this time zooming on spectral features in a broad range of fluxes. The black curves are the unchopped spectra, the red curves represent the chopped observations. In these test cases the total integration time in unchopped mode is twice as long as in the chopped mode.

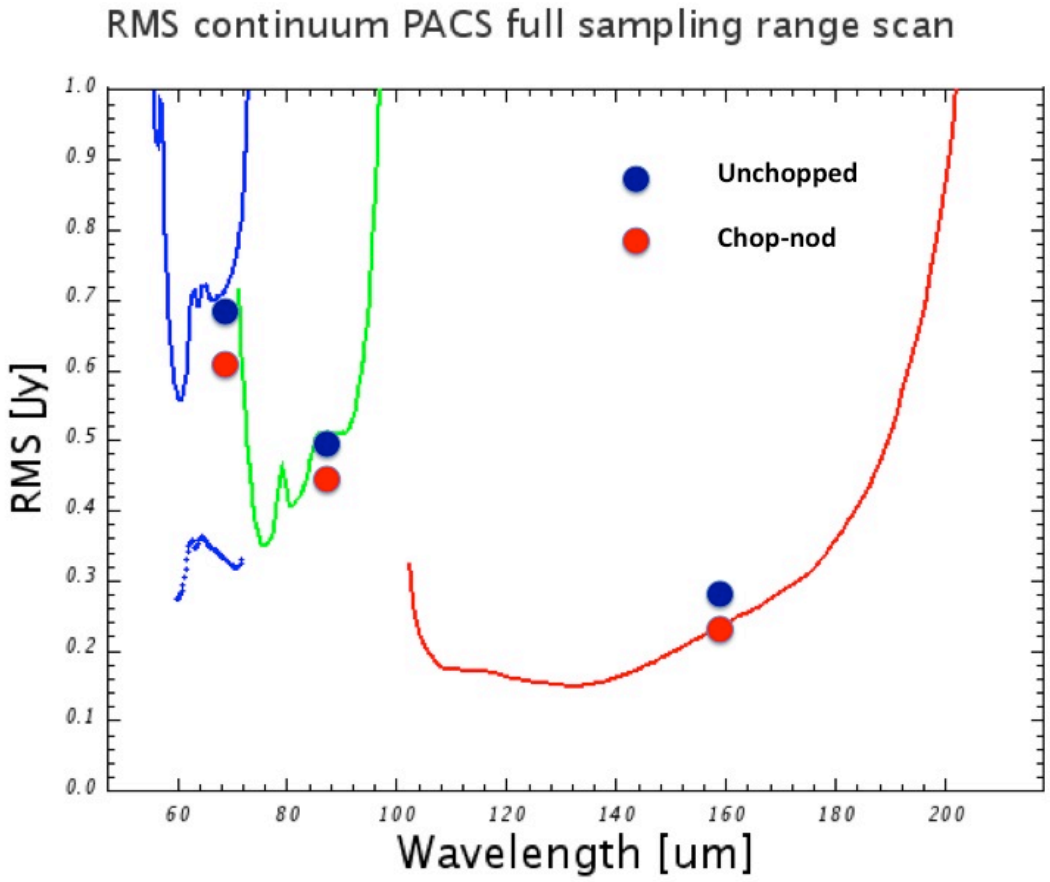

Figure 8. The continuum rms uncertainty for chop-nod and unchopped observations compared with HSpot predictions for an equivalent 450s total on-source integration. The unchopped mode performs well compared with expectations (within ~15%).

5.0 Use and Frequency of Reference "Off" position

5.1 Purpose of the Off Position

It is important to discuss briefly why the "off" position is useful for a given observation. The main reasons are:

1) For bright sources (> 20Jy) differencing the "on" and "off" can provide a source continuum comparable with chop-nod observations. However experiments have shown that for faint sources responsivity drifts on these long timescales make continuum measurements very uncertain and currently cannot be recovered reliably.
2) Observations taken in the "off" position can allow small uncertainties in the relative spectral response function to be corrected in the "on" observation. This is especially valuable for range-scan observations where the subtraction of the "off" can significantly improve the quality of the "on" spectrum as shown on Figure 9.

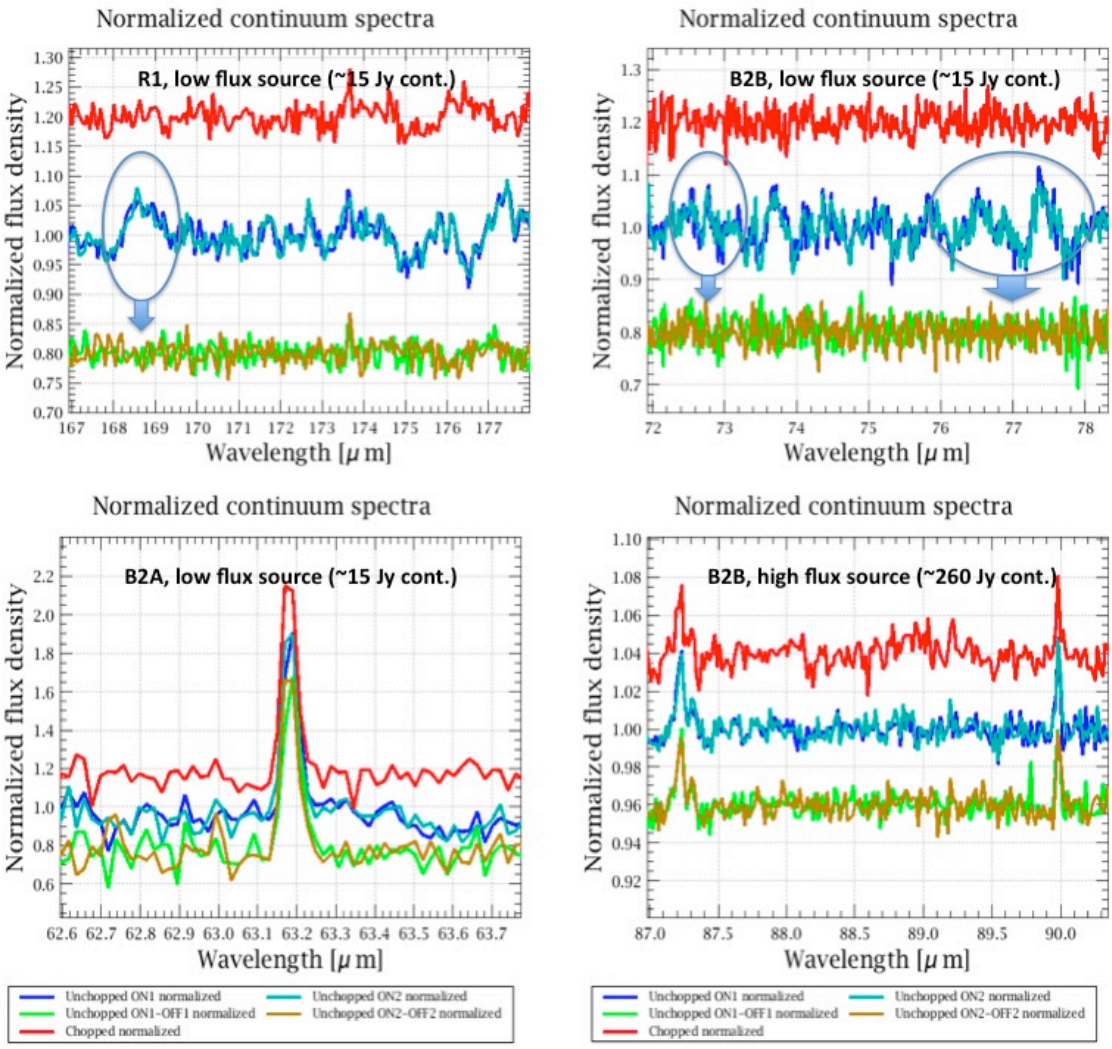

Figure 9. Examples of spectra which show two main features of unchopped scans: (a) the improvement of continuum RMS after applying OFF subtraction and (b) the excellent reproducibility of two ON blocks on the timescale of ~1hr respectively. The red spectra are chopped SED observations, light- and deep blue are spectra obtained on the ON1 and ON2 blocks (each has the same integration time as the chop ON frames), and in the bottom line the two green curves represent the OFF subtracted final unchopped spectra. Flux offsets have been applied for better visualization. Some examples of spectral artifacts (RSRF residuals) are highlighted on the ON spectra (blue ovals). These features are present also in the "off" spectra, but disappear when the two are subtracted (bottom plots). The significantly improves the spectra both in terms of shape and formal rms noise fits.

5.2 Choice of "Off" Frequency

The choice of "off" frequency is a user-defined quantity and will depend on the science goals. If you are primarily interested in line properties then obtaining an "off" at a convenient point in your observational sequence roughly every 30-60 minutes would be ideal. For SED mode or large range-scan, a mandatory "off" should be taken as soon as possible after the main target is observed (as a separate observation—see below) with exactly the same integration time as the "On". Note that it may be possible to observe different clustered targets with the same "Off" if the targets are clustered on the sky together.

5.3 How to Specify the "Off" Frequency in HSpot?

5.3.1 Unchopped Line Scans

For unchopped line scan the AOT is setp up so that the observer gets an "off" at the end of the observing sequence. To ensure that the "off" is observed every 30-60 minutes, it is desirable to arrange that the main observing block does not last more than 30-60 minutes. So for example, for a single "pointed" observation, since a single line takes rough 10 minutes to execute, three to six separate lines could be observed within the AOR. At the end of this period an "off" observation will be executed. If a small map is executed, the user should balance the efficiency of the map making with the need for a frequent "off". It may be more efficient to allow the map to execute to the end of a small map before going to the "off". This would be achieved by setting the "Repeat off position after nth rater position" variable an appropriate value. To give an example. If a single line is observed on a 2 x 2 raster, setting the "repeat off position after nth raster" to 4 will ensure that the "off" is taken at the end of the sequence resulting in an AOR of duration 23 minutes—which would be ideal. If two lines were observed for the same map, the same parameters would lead to an off being taken at the end of the sequence, which in this case would be after approximately 40 minutes—which is still acceptable. Observations with the "off" taken up to 2 hrs from the "on" still seem to produce results that show only a small degradation in S/N ratio, although we recommend keeping the interval as short as possible. In this mode "off" positions of up to 2 degrees from the target may be specified.

As in the previous Wavelength Switching mode, the user, in Line Spectroscopy, can specify an "off" position, either by offset or by RA and Dec specification. Note that by default these offsets are set to zero and it is important that the user specify a non-zero value away from the target. The specification of an "off position" is provided in a special part of the HSpot window for both the "Pointed" and "Mapping" component of the "Set Observing Mode" option.

5.3.2 Unchopped Range/SED Scans

To obtain an "off" observation in the Range/SED mode the "off" observation cannot be specified within the AOR. Instead the user must create a separate "pointed" AOR which is chained to the main observation, or cluster of observations through a group timing constraint. This user-specified "off" must be of the same integration time as a basic observation to which it is attached. This is a mandatory requirement for range-scans and SED mode observations, since it has been found that the subtraction of the "off" (taken with sufficient S/N) will significantly improve the shape of the continuum, correcting for 2nd order effects in the RSRF. It would be possible to use the same "off" for more than one set of "on"s if the "on" observations were short duration range scans. An "off" observation should be taken either before or after a long range-scan observation. For shorter ranges, the user should try to obtain an "off" every 30-60 minutes.

6.0 Saturation Limits in Unchopped Mode

The saturation limits for Unchopped mode are identical to those for Chopped mode observations—see the PACS OM.

7.0 Spatial and Spectral resolution

The user should refer to the best practice guidelines for mapping for the PACS spectrometer as given the PACS OM. Spectral resolution in the unchopped mode is not measurably different from that found for the chopped mode (see PACS OM).

8.0 Calibration and Pipeline for The Unchopped Mode

The PACS ICC is currently developing a calibration strategy for the unchopped mode based on

observations of standard calibration sources. These calibrations files will be made available at the same time that the pipeline is available—in a month or so after the mode is released. The unchopped mode pipeline differs significantly from the Chop-nod pipeline, especially in the way that detector responsivity is measured and methods are currently being tested to find the optimal way to reduce these data.