

## Information Note on Sampling in the HIFI Mapping Modes

17-11-2010

Dear HIFI User,

If your programme employs the HIFI Mapping AOT, namely the On-The-Fly (OTF) mode with any of the available calibration schemes or the Dual Beam Switch (DBS) Raster modes, you are aware of the spatial sampling options in HSpot. The Nyquist and Half-Beam options underwent adjustments in the AOT logic following spectral map performance evaluations by the HIFI ICC, and here we would like to briefly provide a few pointers about the sampling and continuum measurements with these modes that you may not have been aware of during the preparation of your AORs. This note constitutes an update of information that was sent to Key Programme PIs in August 2010.

### 1. Sampling Selection

Through HSpot 4.4, the "Nyquist" option for spectral maps (OTF and DBS Raster) was applying a definition which was not actually Nyquist, but a sampling of HPBW/2.0, or "Half-Beam" sampling applied both along the scanning legs and in the cross-leg direction. The Half-Beam sampling results in a slight under-sampling in pure Nyquist terms, which is typically HPBW/2.4. This was corrected as of HSpot 5.0, where users have the options of true Nyquist spacing, Half-Beam spacing, as well as the more sparser sampling options which remain unchanged. For reference, the table below illustrates the sampling size assumed in the Half-Beam and Nyquist cases (subject to slight change with on-orbit beam calibrations).

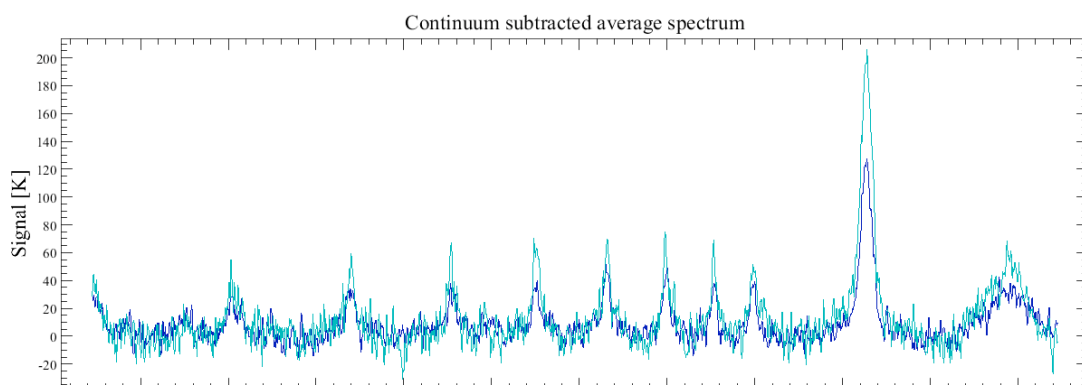
| Band | Beam Width<br>(arcsec) | Nyquist spacing<br>(arcsec) | Half-Beam spacing<br>(arcsec) |
|------|------------------------|-----------------------------|-------------------------------|
| 1a   | 43.5                   | 18.4                        | 22.0                          |
| 1b   | 37.7                   | 15.9                        | 19.0                          |
| 2a   | 33.3                   | 13.9                        | 17.0                          |
| 2b   | 29.8                   | 12.5                        | 15.0                          |
| 3a   | 27.3                   | 11.4                        | 14.0                          |
| 3b   | 24.9                   | 10.4                        | 13.0                          |
| 4a   | 22.5                   | 9.4                         | 11.0                          |
| 4b   | 20.8                   | 8.7                         | 10.0                          |
| 5a   | 19.6                   | 8.0                         | 9.0                           |
| 5b   | 18.6                   | 7.8                         | 9.0                           |
| 6a   | 15.2                   | 6.3                         | 8.0                           |
| 6b   | 14.0                   | 5.8                         | 7.0                           |
| 7a   | 12.8                   | 5.3                         | 7.0                           |
| 7b   | 12.2                   | 5.2                         | 6.0                           |

When the Nyquist option is set to "ON", the sampling between readouts and between scan legs will be ~1.2x closer, and the density of points is typically 1.4x the corresponding Half-Beam case (at the same map dimensions). The different spacings imply a significant difference to observing times or noise performances, since the noise in the maps is estimated on an individual readout basis: the time needed to achieve a fixed noise goal will increase by about 40% in Nyquist maps. Thus, while Nyquist sampling is the recommended option for filled

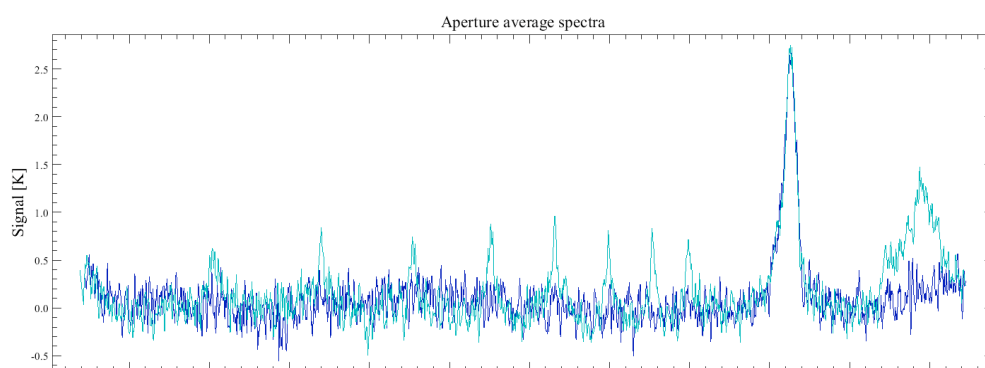
spacing, it is more costly, and we provide a couple of tips on deciding its worth to your programme and how you might consider mitigating the additional observing time if you have already planned Half-Beam AORs.

In simple theory terms, the loss of signal from Half-Beam maps relative to the corresponding Nyquist case should be low, on the order of several percent of the total flux in regions with a relatively smooth surface brightness distribution at the frequency of interest. In reality such smooth environments are probably few, not known *a priori*, and may contradict the point of spectral mapping, so in order to help users decide whether Nyquist sampling is worthwhile from the standpoint of maps in real environments, the ICC has evaluated a number of cases which use both Nyquist and Half-Beam sampling in environments that have diverse degrees of structure at several frequencies, including C<sup>+</sup> 1900.5 GHz, CO 8-7 922 GHz, CH<sup>+</sup> J=1-0 835 GHz, and H<sub>2</sub>O 211-202 752 GHz. Some of the LO settings allow for serendipitous coverage of other species such as methanol and SO<sub>2</sub>, which may have a different spatial distribution compared to the main target transition in the studied environment.

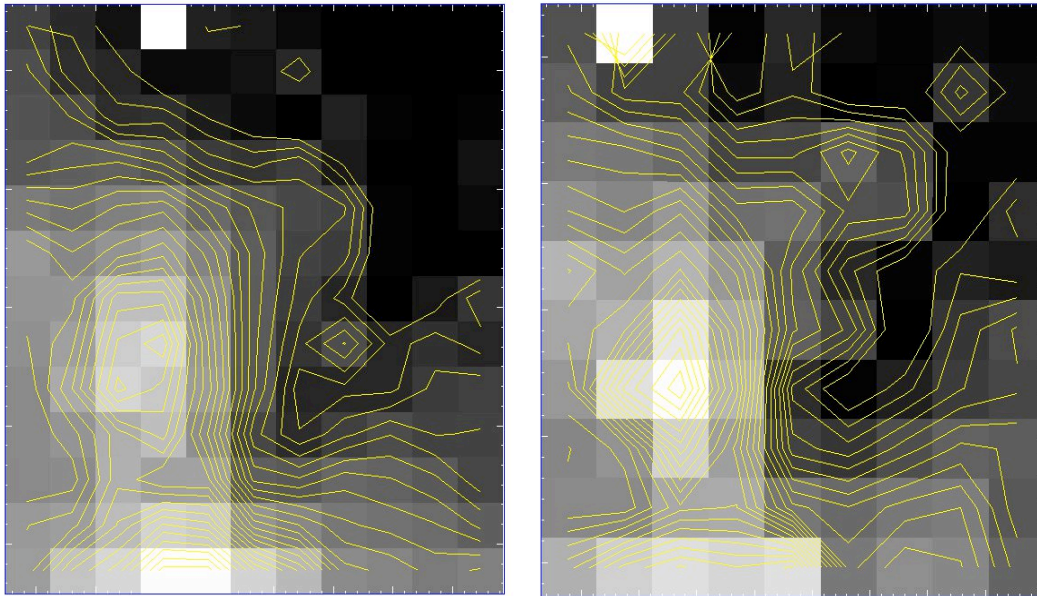
These investigations do indicate that there can be a significant difference of signal properties between the two sampling options. One way to measure this is with averaged and summed spectra over each of the maps in their entirety. The example below compares averaged Nyquist (light blue) and Half-Beam (dark blue) cases. The integrated flux difference is ~20%.



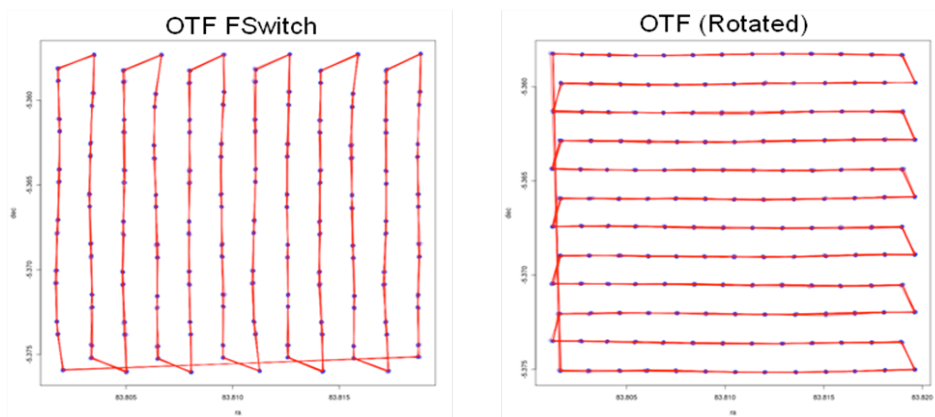
Another way to measure the effects is to make spectral extractions from various locations in each map, over an area which corresponds to the appropriate beam-sized aperture. The next example is from the same Nyquist vs. Half-Beam test, showing that there is a significant difference of intensities of some lines which are spatially distinct from others. The location of the extraction has been chosen where there is a steep gradient in certain transitions within the same covered IF range.



The above comparisons imply that one will notice differences in spatial morphology in each map, which is shown below with velocity channel maps. The map on the left is the Nyquist case, and on the right is the Half-Beam map. Overall the morphology is consistent, however there is structure in the Nyquist map particularly around the emission peak which is unresolved in the Half-Beam case. Some features may be spurious (e.g. upper right corner of the Half-Beam map) where baseline fitting and subtraction has been difficult in certain noisy datasets.



The above examples were obtained with the standard OTF mode (with position switch). We point out that the OTF modes which employ Frequency Switching or Load Chop will have a somewhat different sky sampling scheme, taking into account the calibration loop between ON and OFF sky and internal reference measurements (on the thermal loads or frequency throw) while the telescope is moving. The example below illustrates how this can look over the ON-source map, where each point indicates ON-source readout. The diagram on the left is OTF with position and frequency switching (which would look similar for OTF with position switching and load chopping), on the right is the standard OTF with position switching (rotated by 90 degrees). The OTF with Frequency Switch has a sampling which provides the requested Nyquist spacing *on average*, however in some places the spacing is undersampled while in others it is oversampled. This is a feature of the AOT logic, and should be kept in mind.



If you believe that the Nyquist option is better for your programme, but you have already

planned Half-Beam AORs which have not yet been carried out, we might suggest a time-saving option that does not necessarily involve removing targets (which always works). Namely, we mentioned above that noise is computed on a readout basis, but there will be some signal coupling in the convolved beams with the result that baseline S/N ratios at each point in Nyquist maps should be somewhat better than estimated in HSpot. At this time there are no plans to introduce a resampling method to take this into account in the noise estimation. However, user can take this into account on their own, by reducing the noise or time goals, approaching those of the corresponding Half-Beam case.

## **2. Continuum Measurements**

We simply re-emphasize here that observations which use total power modes are not robust for obtaining accurate continuum intensity levels. This is especially true in OTF maps, where each map point may have only one or two readouts (as given by the `n_cycles` parameter in the HSpot messages after time estimation), and averaging at each point will not reliably compensate for baseline drifts. This is more possible with fixed point observations, if there were many individual scans obtained at the same LO setting and sky position that can then be median filtered, and removal of particularly errant datasets can be afforded. The most difficult cases will be in the diplexer SIS bands 3a/b and 4a/b, and HEB bands 6a/b and 7a/b, and at individual LO frequencies which are known to have stability issues. It is always recommended to perform baseline “clean-up” of mapping observations before gridding into spectral cubes, i.e., removal of residual standing waves and baseline offsets before carrying on with spectral line analyses. We are optimistic that at some point a method that refines the calibrations from the cycling which is driven by Allan variances in the AOT logic to an additional data step in the data processing which makes use of actual drifts during the observation (the so-called mixer current matching technique) will provide improved baseline data quality that may preserve continuum information. Regardless, we continue to strongly recommend the chopped modes (DBS and FastDBS) with the continuum stabilization option, for observations relying on continuum data.

Best regards,

Your friendly HIFI support

## The spur in HIFI band 1a and impact on observations of H<sub>2</sub>O

Science data obtained in band 1a up to OD 474 had to avoid LO tunings above 548 GHz except for in two very narrow windows. The proximity of this spur to the 557 GHz water line made such observations difficult and in some cases impossible. Hence users were encouraged to use the lower sideband of band 1b.

After an extensive engineering effort, hardware settings for 1a were adjusted to suppress this spur without causing an appreciable degradation of the system temperature, with the exception of the last ~2 GHz at the upper end of the band.

It should be noted that there is a mild artifact that remains at 542.378 GHz that occasionally impacts data in the first subband. It is very important to note that the new settings have not been tested extensively on AOTs. ***It is imperative that anyone wanting to use band 1a at any LO setting higher than 540 GHz contact the helpdesk to confirm that spurs will not be a problem.***

We also invite users who moved to band 1b in order to observe this line to reconsider using band 1a if it makes sense for their program. When doing this, users should be aware that the noise temperature in band 1a has slightly changed in the upper frequency range, as a consequence of the spur removal (this is illustrated in Fig. 1 below). The sensitivity is better or similar than that in band 1b for LO frequencies up to 551.9 GHz. Above this frequency, the time penalty in using band 1a rather than band 1b will depend on the requested noise level (typically, there is no significant difference down to noise rms of some tens of mK). It should also be noted that in several OT proposals, the water line was placed at one extreme end of the WBS lower sideband in order to squeeze in another line at the other extreme end of the WBS upper sideband. Due to the double side-band nature of HIFI, the two lines will end up falling on top of each other in the observation. Such a configuration should only be attempted if the user is ***extremely*** confident in the velocity structure of the two lines, and that they can deconvolve them in post-processing. The HIFI ICC very strongly discourages such a practice however.

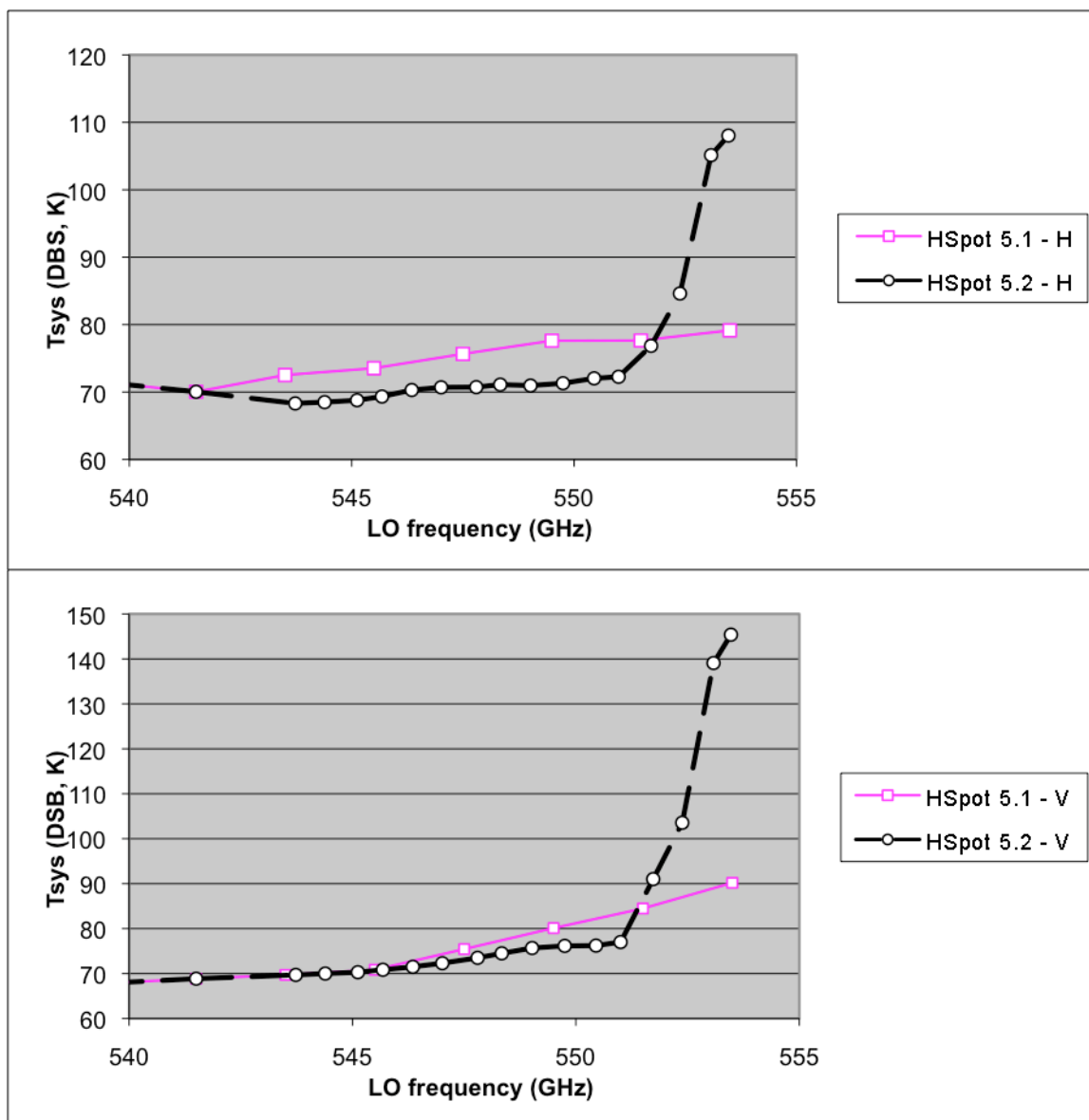


Fig 1: Receiver noise temperatures in band 1a for the H and V polarisations, in HSpot 5.1 (old value) and HSpot 5.2 (new values)