<u>Information note on the HIFI mapping modes:</u>

Dear HIFI KP User,

For Key Programmes such as yours which have submitted On-The-Fly (OTF) spectral map AORs, you are probably aware that the OTF modes are the final of HIFI's observing modes to be validated, following a re-organization of AOT validation for the redundant-side operations. You may also be well aware by now that the evaluation of data acquired in PV has resulted in some necessary adjustments to the AOT logic, that have prevented immediate release until these adjustments could be implemented and tested. In this note we would like to inform you of the changes, and how they will impact the Users of OTF and DBS Raster maps.

1. Sampling

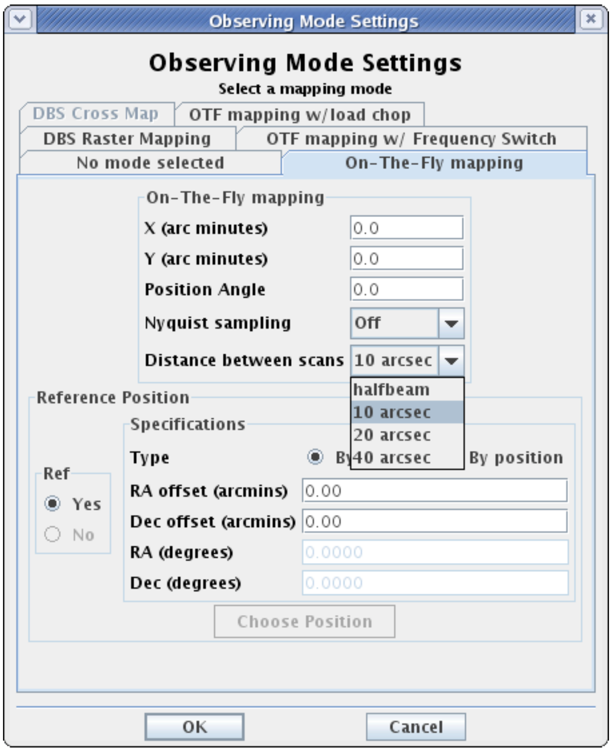
Through HSpot 4.4, the "Nyquist" option for spectral maps (OTF and DBS Raster) was applying a definition which was not actually Nyquist, but a sampling of HPWB/2.0, or "half-beam" sampling applied both along the scanning legs and in the cross-leg direction. The half-beam sampling results in a slight under-sampling in pure Nyquist terms.

The Nyquist definition has been corrected as of HSpot 5.0, so that when the Nyquist option is set to "ON", the sampling between readouts and between scan legs will be ~1.2x smaller than in the half-beam case. This implies a change to observing times or noise performances, since the total number of sampled points will generally increase (within the same requested area) and the noise in the maps is estimated on an individual point basis: the time needed to achieve a fixed noise goal will increase by a factor of about 40%. If a time goal was selected, then the noise per mapped point will be degraded compared to values computed in earlier versions of HSpot. The table below gives the sampling size assumed in the half-beam and Nyquist cases.

Band	HPBW (arcsec)	Nyquist sampling (arcsec)	Half Beam sampling (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

We are contacting you now in order to know whether you would like have your mapping AORs performed with the new Nyquist sampling, with the time or noise change indicated above, or whether you believe that your science can be achieved with the half-beam sampling. Depending on your choice, the options are the following:

- Using the new "half-beam" option.
  If Users wish to remain with half-beam sampling, and therefore maintain the initial observing times as closely as possible, then they may do so by using HSpot 5.0.4 or later to select the new "half-beam" option which has been added to the Observing Modes Setting Panel for spectral maps. The following figure illustrates this modification.



- Using the Nyquist option.
  If the User wishes to employ Nyquist sampling as intended (and corrected), then nothing need be done to the AORs which were submitted with this option "ON". Be aware, however, that observing times at fixed noise goals or else noise at fixed time goals will increase once AORs have been released into the HSC's scheduling pool. It is highly recommended that the User runs time estimation again on all spectral maps in their programme, using HSpot 5.0.4 or later, to assess the differences.

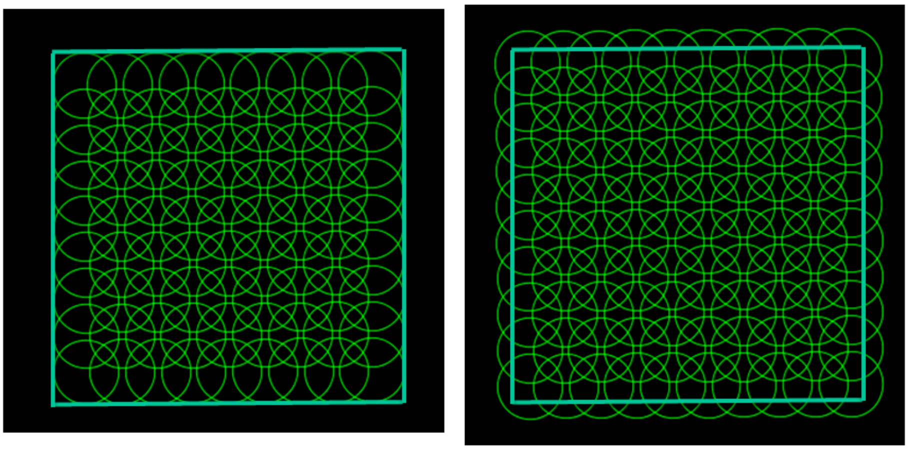
You may find it useful to read the technical note prepared by Rudolf Schieder (see the appendix), which addresses the differences in terms of information loss when using the half-beam option rather than the Nyquist one.

Note, all those maps where no Nyquist sampling was requested (instead selected one of 10", 20" or 40" steps) are not affected by these changes.

The new front-end option will only be available in HSpot 5.0.4, which is the updated AO Call version, to be released in the coming days. In the meantime, we have attached an excel sheet illustrating the time/noise implication for your mapping AORs.

2. Map coverage over requested sampling

HIFI uses a definition that "fills" the requested dimensions of spectral maps at the requested sampling (Nyquist or until now half-beam) in a way that is typically one less readout in each direction (scan leg and cross-leg), compared to the definition commonly used at ground-based telescopes such as IRAM and the CSO. Essentially this is a definition described for HIFI by [(number of points) x sampling], whereas the ground-based definition follows [(number of points - 1) x sampling]. The effect in HIFI maps is that the fully sampled area may be smaller by one readout point in each direction. Note that the sampling may be either Nyquist or half-beam. The figure below illustrate this contrast, where the blue boxes schematically represent a requested area on the sky. On the left is how HIFI fills to the requested sampling, and the right illustrates the conventional filling at ground-based telescopes



At this time, the HIFI ICC does not have plans to make an adjustment of this definition to the ground-based convention, before releasing the OTF mapping modes. The under-filling in ground-based terms may sometimes be partially compensated by two other aspects of the HIFI AOT logic. First, when interpreting the requested map size in terms of a discrete number of points, constrained by the granularity of the telescope commands, the size is always rounded up, i.e. it can occasionally be somewhat larger than requested on average. This applies to all mapping modes, i.e. DBS raster and OTF maps and their various reference scheme options. Second, to compensate for a form of timing "jitter" between instrument and telescope pointing commands, that may often result in a "zig-zag" pattern, one additional readout is added in the scan direction of OTF lines.

How these aspects of the way that the mapping AOTs must work with a complex pointing system naturally depends on each AOR setup, and the recommendation again, is for Users to inspect their AORs in HSpot 5.0.4 or later. The User should examine the message output of time estimation for the resulting map parameters (number of legs, number of readouts, and spacing), visualize this with the AOR overlay utilities, and make adjustments if needed, when either of the Nyquist or half-beam options are used.

Before spectral maps may be schedule, please inform us of your preferences concerning Point 1, on the Half-Beam vs Nyquist option, preferably before July 10th.

Best regards,

Your friendly HIFI support

Appendix: Comment about Nyquist Sampling – R. Schieder

In many cases Nyquist sampling is recommended when measuring complete maps of a source or fully sampled spectra with a spectrograph. The initial idea about Nyquist sampling was that one has data which are derived by means of a "Delta-comb" so that there is zero overlap of the spatial or frequency response function of the instrument. The assumption is therefore that with each position one obtains 100% information about the signal strength at that position. This is only a (nearly) correct assumption, if the spacing between the data points is large in comparison with the filter width of the instrument. The situation changes when dealing with a denser sampling grid. The main question is how much additional information one can derive when increasing the density of the grid. For an estimate we can use the "Modulation Transfer Function" (MTF), which we define as the convolution of the instrument filter function *F(x)* with a sinusoidal power distribution of the signal at a (spectral or spatial) frequency *v*.

For the MTF we need to calculate the integral

$$M(\nu) \;=\; \int_{-\infty}^{\infty} \cos(2\pi \cdot x \cdot \nu) \cdot F(x) \cdot dx$$

We might approximate the filter function with a Gaussian:

$$F(x) \;=\; \frac{1}{\sqrt{2\pi \cdot \sigma^2}} \cdot \exp[-x^2/2\sigma^2] \;=\; \frac{1}{\delta_{\mathrm{Res}}} \cdot \exp[-\pi \cdot x^2/\delta_{\mathrm{Res}}^2].$$

The so called "resolution bandwidth" δ_{Res} of a filter (or "beam solid angle" of a telescope) is given by :

$$\delta_{\mathrm{Res}} \;=\; \frac{1}{F_{Max}} \cdot \int_{-\infty}^{\infty} F(x) \cdot dx$$ as we have already used for the definition of *F(x)*.

With this we get now:

$$M(\nu) \;=\; \frac{1}{\delta_{\mathrm{Res}}} \cdot \int_{-\infty}^{\infty} \cos(2\pi \cdot x \cdot \nu) \cdot \exp[-\pi \cdot x^2 / \delta_{\mathrm{Res}}^2] \cdot dx \;=\; \exp[-\pi \cdot \delta_{\mathrm{Res}}^2 \cdot \nu^2]$$

The MTF is 1 at small spatial frequency *v* and approaches zero with large *v*.

Nyquist sampling defines the distance between adjacent data points, and one usually assumes that one should have two data samples per maximum frequency period v_{Max}. If the instrument has a resolution δ_{Res}, it sounds plausible that the spacing of the data points should be $1/2 \cdot \delta_{Res}$. In this case we have $v=1/\delta_{Res}$, and we get for the MTF at this spatial frequency:

$$M(\nu = 1/\delta_{\mathrm{Res}}) \;=\; \exp(-\pi) \;=\; 4.3\% \text{ !!}$$

Thus, the measured amplitude of a signal contribution at spatial frequency $1/\delta_{Res}$ is very small. Consequently, it is not worthwhile to consider fully sampled maps, because the derived additional information is practically zero, but is very costly on the other hand in terms of observing time. If we increase the grid spacing to δ_{Res} ($v=(2\delta_{Res})^{-1}$), the response becomes 45.6%, which is still not very satisfying but already useful. Certainly, real filter functions are not Gaussian, but in all standard cases the approximation is close enough to reality. The discussion here is done only in one dimension, but things don't change significantly, when talking about two-dimensional maps.

The result above can be compared with the value of the correlation function of two adjacent pixels. If we assume two identical pixels spaced by a distance *s*, we have for the correlation between the two data:

$$g_{12}(s) = \frac{\int_{-\infty}^{\infty} F(x+s/2)\cdot F(x-s/2)\cdot dx}{\sqrt{\int_{-\infty}^{\infty} F^2(x+s/2)\cdot dx}\cdot\sqrt{\int_{-\infty}^{\infty} F^2(x-s/2)\cdot dx}} = \exp[-\pi\cdot s^2/2\delta_{\mathrm{Re}s}^2]$$

Thus, the correlation of two data points at Nyquist sampling is

$g_{12}(s=\delta_{Res}/2) = 67.5\%$

Correlation means here, that the information found with the second data point is in more than two thirds identical with that of the first point. With $s = \delta_{Res}$, the correlation is only 20.8%.

As a rule of the thumb one might consider a pixel spacing at a correlation of 0.5. This suggests a spacing of $s \approx 2/3\cdot\delta_{Res}$. The MTF has there a value of 17.1%.