HIFI AOT Release Note I

DBS Observing Modes

Abstract

This document summarizes the readiness of the HIFI DBS Observing Modes for PSP/SDP/RP observing, based on analysis of AOT testmode observations and engineering tests carried out over the first two blocks of the Performance Verification phase on redundant HIFI subsystems.

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Revision history

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Draft	24/02/2010	First version for AOT readiness review with HSC.	PM
1.0	08/03/2010	Updates and revisions with HIFI ICC inputs	PM

Contents

1. Preface and Acknowledgements

The special circumstances of HIFI's switch to redundant side operations and resuming with a compressed Performance Verification phase and accelerated Observing Mode release has been supported by not only the core group of HIFI Calibration Scientists and Instrument Engineers over the "long haul", but also the KP team apprentices who have been variously present at the HIFI ICC in the Fall of 2009 and during PV-II starting end-January 2010, and also the HIFI software development team who have been available at all times. AOT test planning has been done in consultation with the KP PIs coordinated by X. Tielens, Instrument P.I. F. Helmich, Project Manager P. Roelfsema, and with the Mission Scientist J. Cernicharo. These persons should be acknowledged, as having directly supported the flight qualification of HIFI as a science instrument.

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2. Introduction

The HIFI Dual Beam Switch observing modes have been released in each of the Point, Mapping, and Spectral Scan AOTs for carrying out PSP/SDP/RP observations starting February 28, 2010. This note summarizes the important performance aspects and caveats, as they are understood at the beginning of the first block of HIFI PSP observations. The audience for this note is the HIFI users and Herschel Science Centre.

The results presented and discussed below have been obtained using the HIFI pipeline and tools available in the operational HCSS 2.X track (2.0 through 2.4), with the intention for users to be able to reduce PSP data and reproduce results consistently with the version of the SPG at HSC. In some applications, only jython scripts are currently available (e.g., data cleaning and interactive baseline fitting), and certain tools in CLASS have been tested and used with observations exported from the HCSS to CLASS FITS.

Since the HIFI PSP scheduling overlaps with HIFI PV and there are many calibration observations still to be carried out and analyzed, and not all of the current results are understood, it is expected that this note will be updated.

To summarize, all of the DBS modes and options they are offered in HSpot are released in all LO bands for science scheduling, with following exceptions and conditions:

- LO signal purity
  - **Band 5b is not released for PSP-I or PSP-II**, due to signal purity issues that lead contamination from frequencies which are not part of the commanded tuning. Mapping observations in 5b done on CO (11-10) to verify pointing calibrations showed no CO line although the neighbouring transitions (in other bands) were easily detected. This points to a purity problem around those LO frequencies around 1261GHz, but may also apply to other frequencies in that band.
  - Similarly, Band 7b is shows evidence of impurities when the LO is tuned in the ranges of [1869 – 1873] and [1879 – 1886] GHz, adversely affecting blue/red-shifted C+ observations (or presenting false information there). Thus **AORs which request a tuning over these ranges in 7b** (primarily wide Spectral Scans from PSP-I/II) are also on hold.
  - Several other frequencies or frequency ranges are suspect to contain unwanted LO signals, summarized below.

- The initial results from comparing performances of the normal (or slow) chop DBS with FastDBS modes indicate that the latter generally perform better with respect to correction for electrical standing waves in Bands 6 and 7. This will be explained further below. **The recommendation at this time is to only use FastDBS in the HEB bands.**

3. Spectral Purity

There are tunings of the LOs in several sub-bands that have been shown to produce more than one frequency. In these cases, an observed spectrum will have the features of a different unknown (and possibly unstable) frequency. When this is the case the mixer gain at the desired frequency will be unknown and it will not usually be possible to calibrate the flux accurately. Most of the impure regions were corrected in the ILT, TV/TB and CoP test campaigns; however, several frequencies remain to be addressed or cannot be addressed due to hardware safety considerations. The known impure frequencies include:

- **Band 3b**: LO frequencies near (±1 GHz) 941 and 952 GHz.
- **Band 4b**: LO frequencies above 1114 GHz (extreme upper end of tuning range).
- **Band 5a**: LO frequencies near (±2 GHz) 1135 GHz and Frequencies near (±2 GHz) 1206 GHz.
- **Band 5b** contains a number of frequencies covering a good fraction of the band. The full extent remains unknown so this band is currently unusable and was not included in the AOT release.
- **Band 7a:** LO frequencies between 1710 and 1720 GHz and between 1755 and 1759 GHz.
- **Band 7b:** LO frequencies between 1869 and 1873 GHz and Frequencies between 1879 and 1886 GHz.

The scheduling implications are summarized as follows:

- Spectral scans in bands 3b, 4b and 5a may be scheduled as-is, and possibly discard the spectra taken at unruly LO frequencies. This will imply some noise degradation after the spectrum deconvolution.
- All AORs in band 5b are not releasable yet. Parametric scans will be carried out in mid-March to seek more optimum multiplier settings which reduce the tuning instabilities.
- AORs in bands 7a and 7b already scheduled in PSP-I and PSP-II will be carried out as-submitted, with the same message as given above for 3b, 4b, and 5a. For AORs which still need to be scheduled, the following should be considered in consultation between the HSC and KP teams:

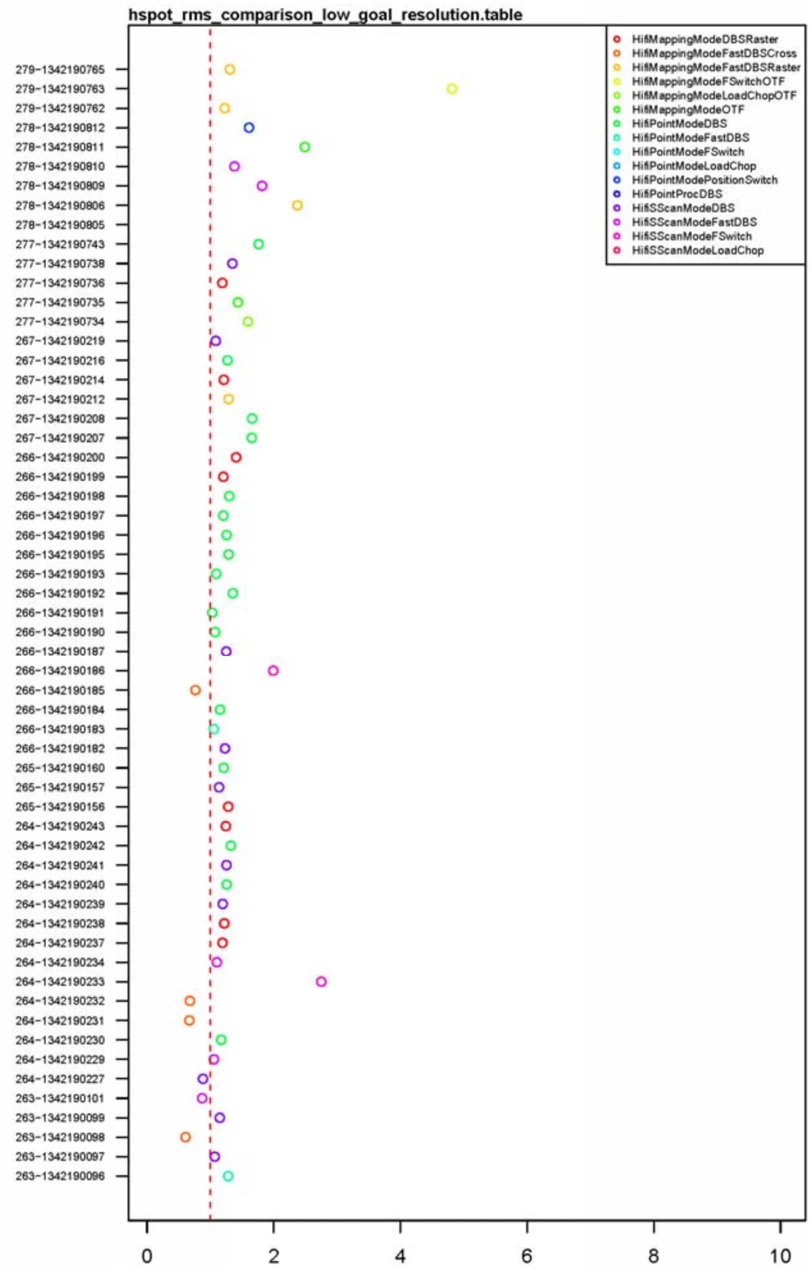
- Spectral Scans which run through the7a/b ranges listed above are recommended to be partitioned into two or more AORs, to avoid the impure areas until such time that engineering tests still to be executed eliminate the unwanted signals. As a consequence there will be a slight penalty due to the slew time tax charged at each additional AOR, and a degradation of the achieved noise at the edges of the deconvolved spectra due to a coarser redundancy. Once nominal LO purity has been established, the missing areas may be scanned if desired. Presently this means that LO tunings only over the following ranges are advised:
  - Band 7a: [1701.2 – 1710], [1720 – 1755] and [1759 – 1793.8] GHz
  - Band 7b: [1793.2 – 1869], [1873 – 1879] and [1886 – 1901.8] GHz. If no scientifically important spectral features are expected in the [1873 – 1879] GHz range, it is also possible to simply skip the whole [1869 – 1886] GHz area. This is up to the user.
- For fixed frequency AORs (Point and Map AOTs), the main lines of interest should be moved into the image bands to an LO frequency which falls in an area not affected by purity issues. If this is not possible, and the requested tuning falls into the impure regions listed above, the AOR should be placed on hold due to the high risk of scientifically fatal and un-correctable mis-calibrations, until such time that the impurities have been fixed.

4. Noise performances

4.1 Fixed LO observations

HSpot provides noise estimates on a single sideband (SSB) main-beam brightness scale for combined H and V polarization spectra. Observations carried out in PV-II were analysed in order to verify these predictions, which drive observing time at goal and maximum spectral resolutions entered in HSpot by the user. The 1 GHz reference option has almost always been used in the noise predictions, which means that the baseline in only one WBS sub-band is considered for stability instead of the full IF, to take standing waves within that 1 GHz window into account. This is recommended for most observing situations except, when lines are very broad (such as from external galaxies or fast outflows).

Figure 1 shows the ratios of observed over predicted noise, at the goal and maximum spectral resolutions (entered in the AORs).


hspot_rms_comparison_low_goal_resolution.table
HifiMappingModeDBSRaster
HifiMappingModeFastDBSCross
HifiMappingModeFastDBSRaster
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HifiMappingModeLoadChopOTF
HifiMappingModeOTF
HifiPointModeDBS
HifiPointModeFastDBS
HifiPointModeFSwitch
HifiPointModeLoadChop
HifiPointModePositionSwitch
HifiPointProcDBS
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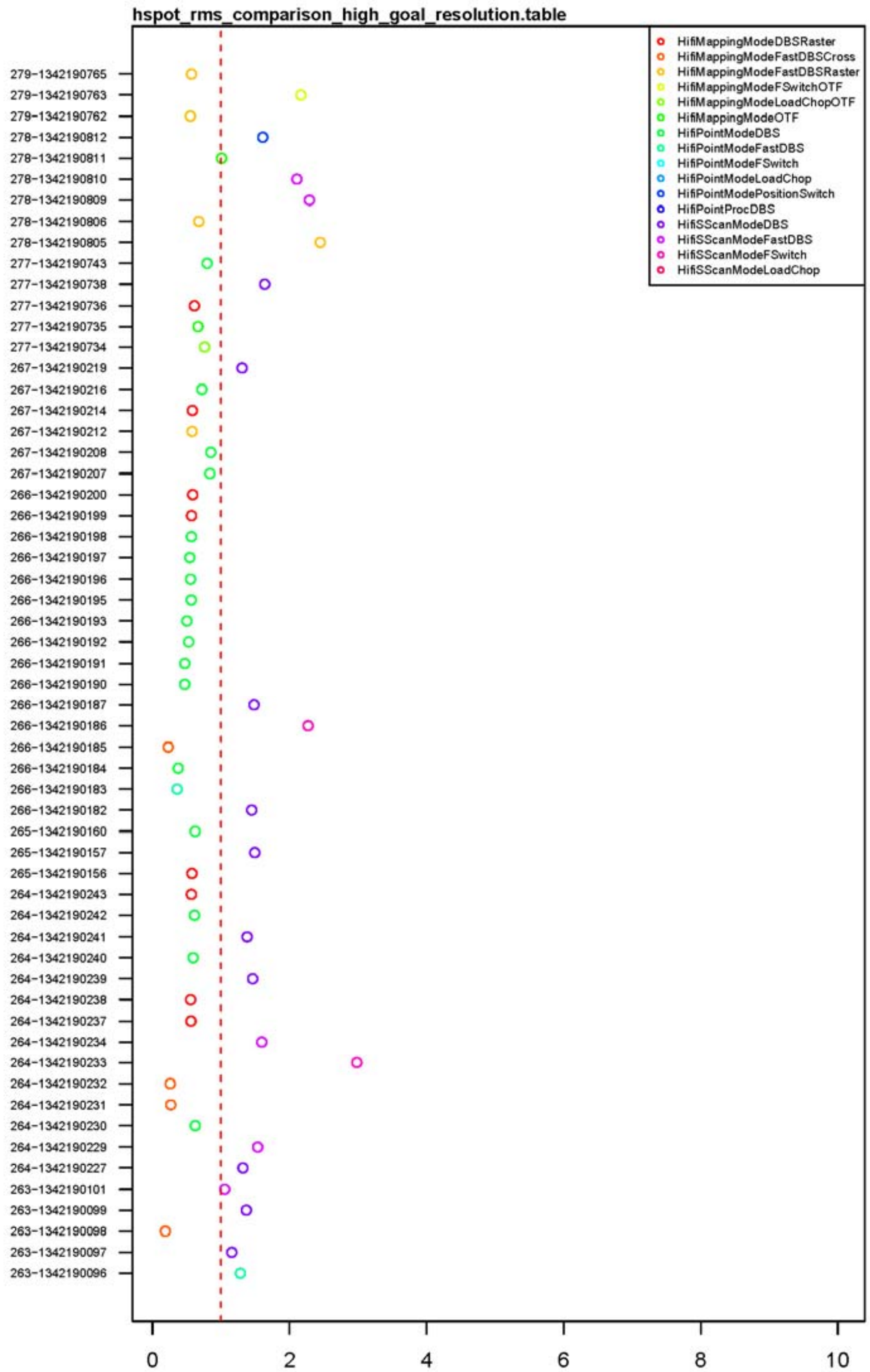


Figure 1 Ratios of measured to predicted (HSpot) noise for all DBS observations carried out in PV-II through February 25, with data smoothed to the goal low resolution (top) and high resolution (bottom).

Note in the plots shown above that noise values for the Spectral Scans have been measured from the dual sideband (un-deconvolved) H+V averaged spectra at the reference frequency where noise is predicted in HSpot, and have thus been appropriately scaled by a factor [2 x redundancy] $^{-1/2}$.

Normally one would measure the noise at the reference frequency in the single-sideband, H+V averaged spectra (see Sec. 4.2). Numbers for the Spectral Scans are anyway given above to show the reasonably good agreement between predicted and measured noise before deconvolution, which may itself influence data quality depending on pre-treatment of artefacts, baseline drifts, standing waves, etc.

4.2 Spectral Scans

The noise in the Spectral Scans when measured before sideband deconvolution scales with [2 x redundancy] $^{-1/2}$, to the SSB noise when the gains are equal (0.5). When the gains deviate from unity, the deconvolution algorithm should model these as well and the same scaling should apply. So far there are no indications of a departure away from unity that can be distinguished from many other data qualities.

While the analysis of the ~4 dozen Spectral Scans taken in PV-II so far is still ongoing, the deconvolved SSB RMS values are found to be in good agreement, but also sometimes 1.5 to 2 times higher than the HSpot predictions in Bands 1-5. A few examples are tabulated below for comparison to the points in Figure *1*. (note that the noise has not necessarily been measured at the reference frequency, but rather close to the middle of the covered range). Very preliminary results indicate that the HEB Bands 6 & 7 may yield even higher SSB RMS noise values - between 2-3 times than predicted by HSpot. Further tests with the software, and observations still to be carried out, are needed to confirm these findings.

1342190187 1b DBS R = 8, H+V HSpot T_{mb} noise @ 1 MHz = 22mK

Freq	H+V avg (T_{mb})
558.35	25.48
568.56	20.26
578.00	21.45
584.83	27.87

Ratio: 0.9-1.3

1342190239 2a DBS R = 8, H+V HSpot T_{mb} noise @ 3 MHz = 9 mK

Freq	H+V avg (T_{mb})
683.75	9.67

Ratio: 1.07

1342190241 2a DBS R = 3, H+V HSpot T_{mb} noise @ 3 MHz = 9 mK

Freq	H+V avg (T_{mb})
683.75	10.53

Ratio: 1.17

1342190215 5a DBS R = 8, H+V HSpot T_{mb} noise @ 3 MHz = 43 mK

Freq	H+V avg (T_{mb})
1163.90	78.08

Ratio: 1.81

1342190904 5a FastDBS R = 8, HSpot H+V T_{mb} noise @ 3 MHz = 46 mK

Freq	H+V avg (T_{mb})
1163.90	74.60

Ratio: 1.61

It is clear that effective sensitivity is enhanced after sideband deconvolution. Lines that are undetectable in individual double sideband spectra may become visible in deconvolved spectral as shown in Figure *2*.

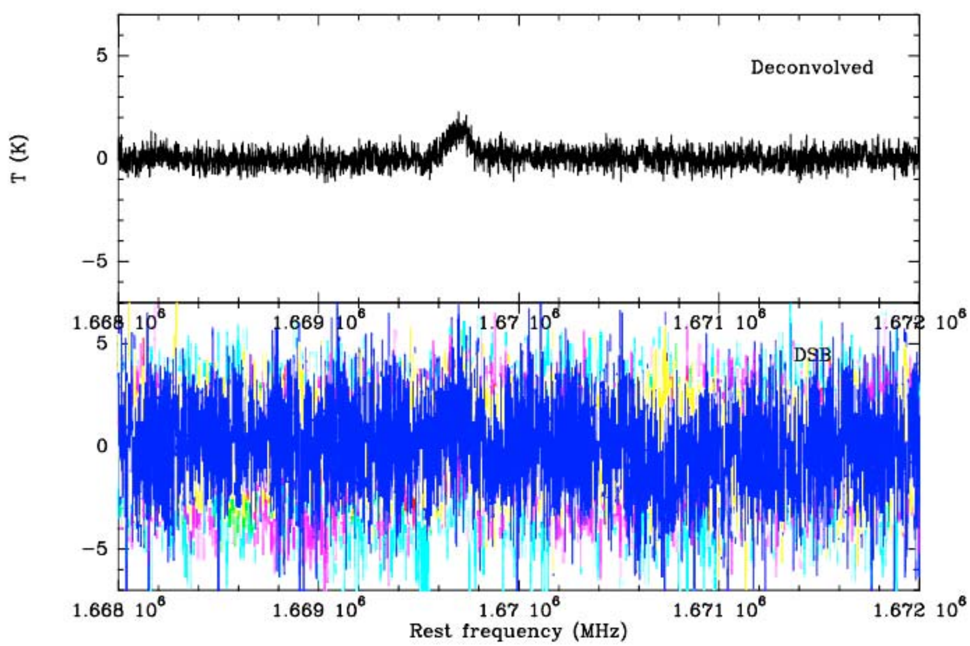


Figure 2: A survey of band 6b double sideband spectra taken at redundancy 8 with a fast-chop is overplotted in color in the lower panel, and the deconvolved single sideband spectra shown in top panel. The water line, invisible in the DSB dataset, is brought-out by the deconvolution.

There is not yet a clear distinction in noise performances between which use DBS and FastDBS observations (whereas it is reasonably clear that there is no distinction for fixed LO observations), but fast-chopping anyway will be more effective at removing standing waves in Bands 6 and 7.

Observers should keep in mind that the production of good SSB spectra is highly dependent on the removal all artefacts: standing waves, spurs, and the removal of all continuum baselines (linear or non-linear) prior to performing the deconvolution reduction step. An example of the value of "cleaning-up" spectra prior to deconvolution is shown in Figure 3.

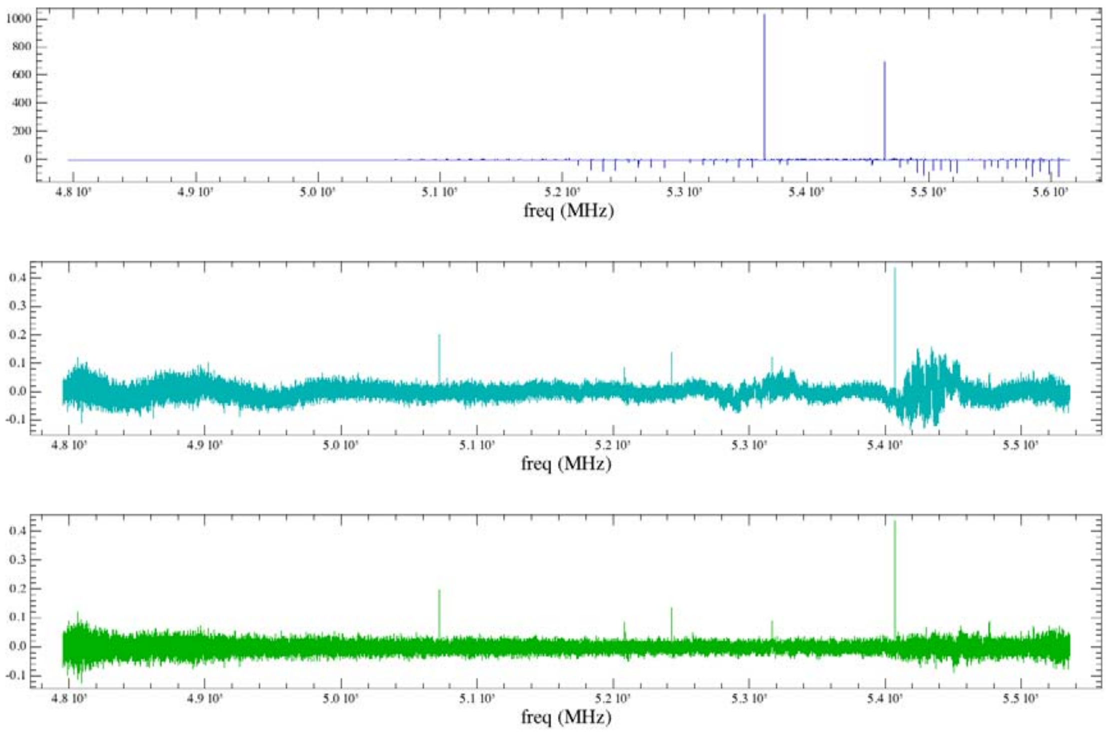


Figure 3: Band 1a spectral scan in various states of cleaning. The top plot shows the raw output from deconvolution. The effect of the spurs is obvious, as they echo throughout the solution. The centre plot has the spurs flagged-out, and the solution is much better, though issues with baselines are apparent. We applied a simple baseline removal routine, and the result is the spectrum on the bottom.

Summarizing the Spectral Scan observational results:

- The results have been generally very good, with nearly the expected noise levels in the spectral surveys regularly reached in most bands (within a factor of 1.5) with very comparable results obtained in both polarizations
- Both broad surveys (20-80 GHz in width) and narrow surveys (4-19 GHz in width) have been successfully observed and deconvolved. These include the so called "mini-surveys" which sample a narrow 4-6 GHz band without moving completely off of the target line while observing at high redundancy (R=12). These mini-surveys are useful in ruling out line blending and frequency ambiguities.

- No “ghost lines”, symptoms of instabilities or insufficient sampling, have been found in any survey. When spectral artefacts and bad baselines are removed completely from the input prior to deconvolution, the deconvolution yields flat baselines with neither ringing, nor any added repetitive noise structures.

5. Performance/Sensitivities at IF Edges

In the diplexer bands 3, 4, 6 and 7, as substantial increase in system temperatures and thus decrease in sensitivity occurs towards the edges of the IF bandpass.

For Bands 3 and 4, the IF bandpass span is 4 GHz (4 – 8 GHz), and the last 500 MHz at either side, between 4.0-4.5 GHz and between 7.5-8.0 GHz, induces a significant increase of baseline noise since the diplexer mechanism introduces extra losses in those locations, and Tsys can increase up to 50-100% as compared to the central part of the IF (see Figure 4).

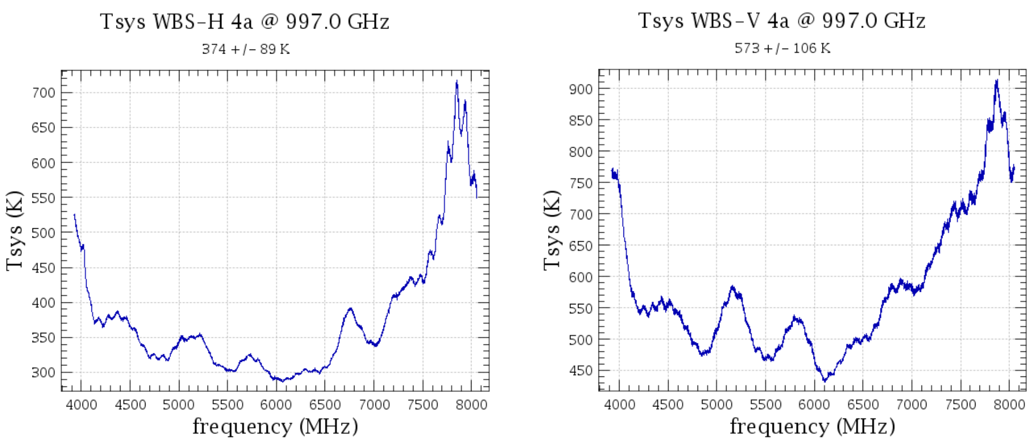


Figure 4: Noise temperatures in Band 4a, at 997 GHz.

Additional drawbacks include degraded stability performance (stronger standing waves and poorer baseline performance). Note that those stability issues can be mitigated by using Fast-DBS, but not the sensitivity degradation.

Thus it is not so much a lien or caveat on the Observing Modes, but rather a recommendation to avoid placing lines in the last ~500 MHz on either end of the IF, in any diplexer band using the Point or Map AOT. In cases where two lines are being targeted in the edges of the upper and lower sideband in a single AOR, it is better to devise separate AORs for each line despite the additional 180 sec slew tax, since time is not being saved in a single AOR when the noise and standing waves are impeding spectrum quality. Figure 5 shows an example of the kind of setup which is not recommended.

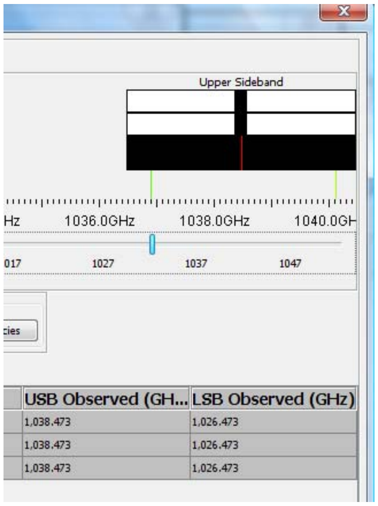


Figure 5: Example of a setup to avoid in Point or Map AORs, targeting lines at the edges of the IF in either or both of the USB or LSB in diplexer bands. Two separate AORs should be devised.

6. Standing Wave Residuals after Calibration (Level 2)

The HIFI AOTs and pipelines are designed to minimize standing waves in the astronomical data. Because SiS and HEB mixers produce different waves, they are discussed separately.

6.1 Bands 1-5 (SiS mixers)

Bands 1-5 data, taken in DBS mode, generally do not show standing waves at Level 2. Exceptions are sometimes observed, however, and in these cases the user can remove the waves with the sine wave fitting task 'FitHifiFringe' in HIPE. Two cases are shown below.

- In Band 4b the diplexer causes a 650 MHz ripple. Figure 6 shows a sine wave fit (red) relative to a baseline (green), automatically determined with FitHifiFringe.

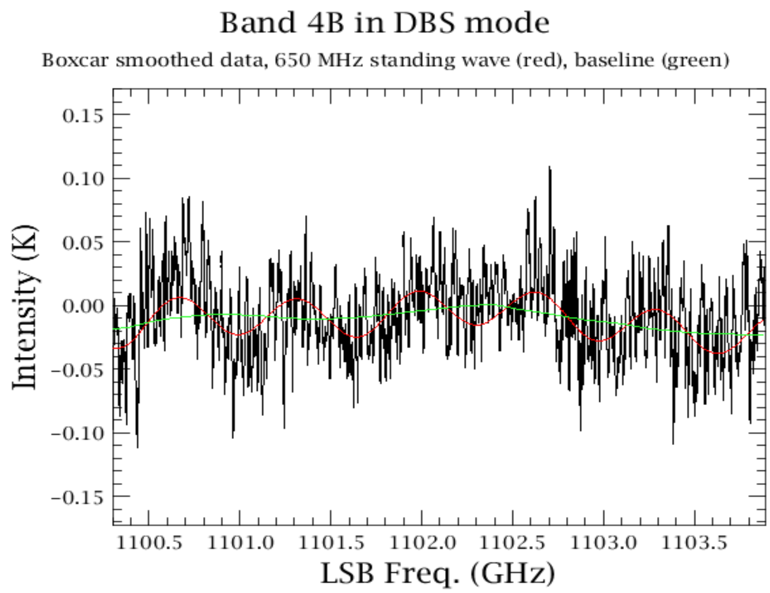


Figure 6: Standing wave residual at Level 2 in a DBS observation, with the fitted sine wave (red) relative to a smoothed baseline (green).

- Strong continuum sources show the effect of ripples in the passband calibration. The periods are typically in the 90-100 MHz range, and the amplitudes are at most 2% relative to the continuum. See Figure 7 below for a case where 92 and 98 MHz since waves are present.

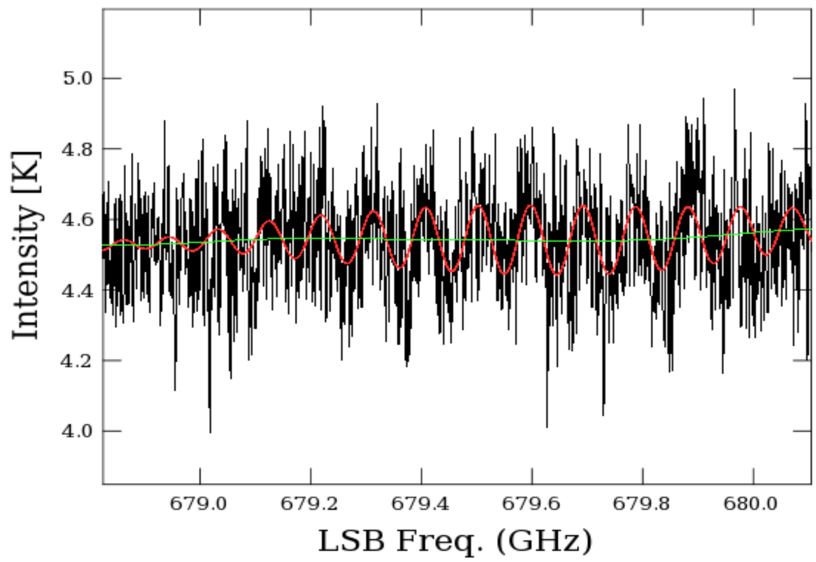


Figure 7: Strong continuum source with two standing wave components (red), relative to the baseline (green).

6.2 Bands 6-7 (HEB mixers)

Bands 6-7 are less stable than bands 1-5, and Level 2 data occasionally show residual waves. Examples are shown in Figure 8 for portions of Bands 6a and 7b. The latter was box-car smoothed by 5 channels.

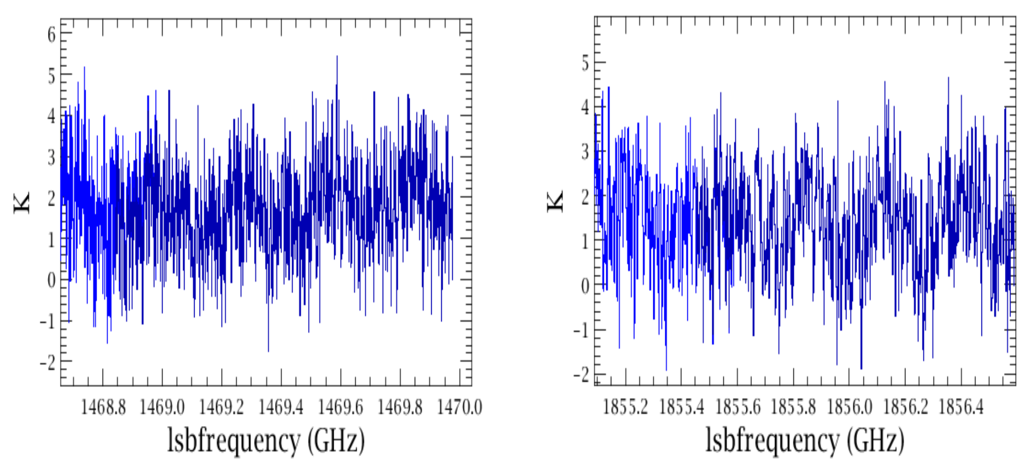


Figure 8: Standing wave residuals in Band 6a (left) and 7b (right).

These 'electronic' standing waves have periods of ~300 MHz, but they are not sine waves and 'FitHifiFringe' can only approximately remove them. A promising method ('current matching technique') is being developed to remove these waves in the pipeline.

As for the presence of these waves the following general guidelines can be given:

- Band 6b is most stable and is least affected.
- FastDBS mode spectra tend to show weaker standing waves than 'slow chop' DBS mode spectra
- In Band 7, spectra taken with the vertical polarization spectrometers tend to show stronger waves than from the horizontal polarization. Sometimes this effect is very strong, as shown in the Band 7a observations below (Figures Figure *9* and Figure *10*).

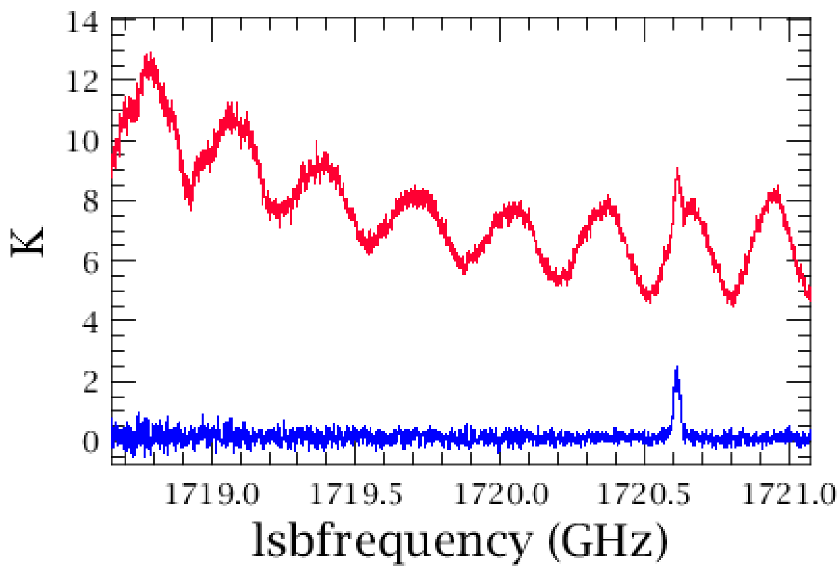


Figure 9: Standing wave pattern in the Level 2 (after calibration) in Band 7a for WBS-V (red) and WBS-H (blue).

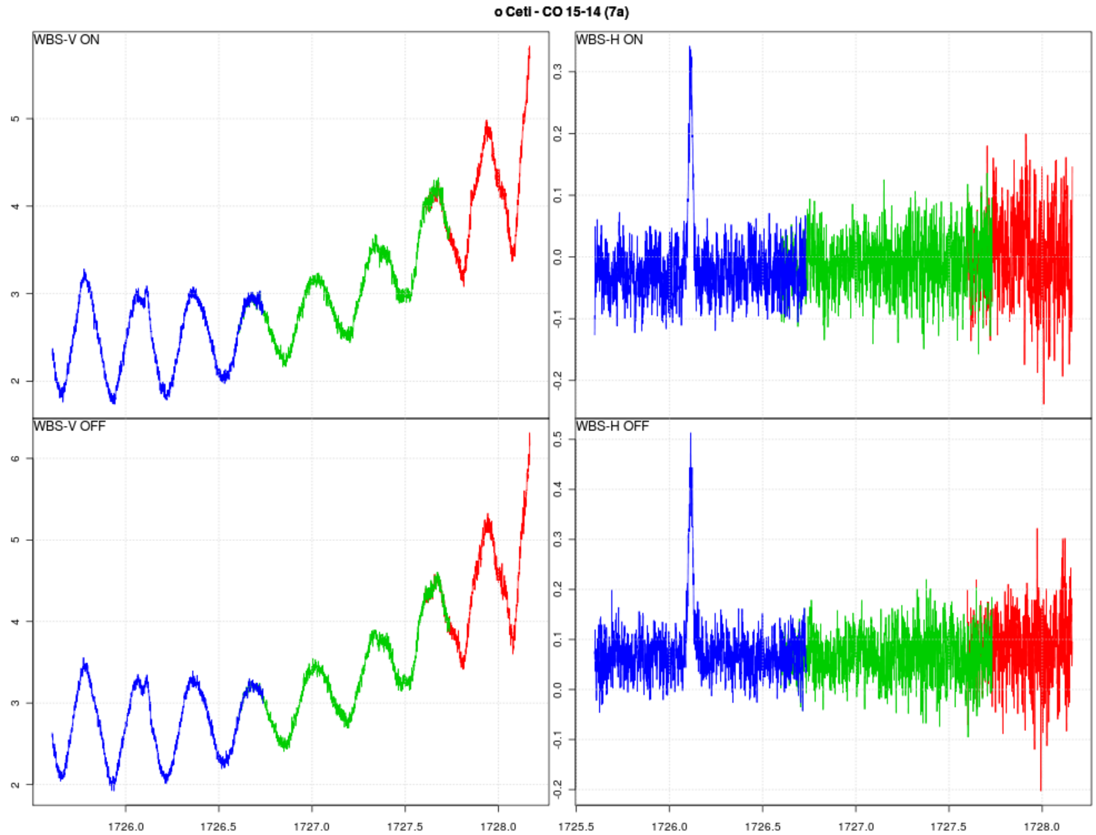


Figure 10: During the analysis of the FPG-3 raster map done on OD 278 (obsid 1342190805:Fpg3_M_FastDBSNoC_7a_CO_15-14_oCeti_3x3) it was found that the quality of the WBS-V has much poorer data quality, due to a large ripple, than WBS-H. The latter shows hardly any ripple at all. These data were processed using the "level1WithoutOffSubtr" algorithm and the attached plot shows both the ON and OFF phase for both polarizations. As can be seen the ripple in V in the ON and OFF phase will not cancel when averaged. When subtracted, most of the ripple is gone, but so is the line.

7. Pointing

7.1 Focal Plane Geometry Calibrations "Part 3"

In PV-II a first set of FPG-3 observations were carried out, using CO and H_2O emission lines from AGB stars to check the pointing in a number of HIFI bands. They serve the following purposes:

- Check the performance of the (Fast) DBS raster and DBS cross mode.
- Establish the S/N of the observed spectral lines and their usefulness for pointing verifications.
- Build up a database of pointing results on which eventually a SIAM update for the HIFI aperture entries may be based.

- Provide a set of raster maps to cross-compare with OTF mapping modes.

7.2 Observations

OD	ObsId	Source	Size	Line	Band	Mode	Comment
264	1342190237	o Ceti	5 x 5	CO 6-5	2a	DBS	
264	1342190238	o Ceti	3 x 3	CO 6-5	2a	DBS	
264	1342190243	o Ceti	3 x 3	CO 6-5	2a	DBS	
265	1342190156	NML Tau	3 x 3	CO 11-10	5b	DBS	no detection
265	1342190161	o Ceti	3 x 3	CO 9-8	4a	DBS	
266	1342190179	o Ceti	3 x 3	CO 5-4	1b	DBS	Failed due to SEU
266	1342190199	o Ceti	3 x 3	CO 6-5	2a	DBS	
266	1342190200	NML Tau	3 x 3	CO 6-5	2a	DBS	
267	1342190212	o Ceti	3 x 3	CO 7-6	3a	FastDBS	
267	1342190214	o Ceti	3 x 3	CO 10-9	5a	DBS	
278	1342190805	o Ceti	3 x 3	CO 15-14	7a	FastBS	
278	1342190806	NML Tau	3 x 3	H2O 303-212	7a	FastDBS	
279	1342190762	o Ceti	3 x 3	CO 14-13	6b	FastDBS	
279	1342190765	NML Tau	3 x 3	H2O 212-101	6b	FastDBS	
281	1342190844	o Ceti	3 x 3	CO 5-4	1b	DBS	
283	1342190902	R Dor	cross	CO 10-9	5a	FastDBSX	
283	1342190903	R Dor	cross	CO 10-9	5a	FastDBSX	
283	1342190908	R Dor	3 x 3	CO 7-6	3a	FastDBS	

Table 1: List of FPG-3 observations carried out in PV-II, Blocks 1 and 2.

Frequency	El	transition	band
MHz	*cm-1*		
576267.931	38.4481	5-4	1b
691473.076	57.6704	6-5	2a
806651.806	80.7354	7-6	3a
1036912.393	138.3904	9-8	4a
1151985.452	172.9780	10-9	5a
1267014.486	211.4041	11-10	5b
1611793.518	349.6975	14-13	6b
1726602.507	403.4612	15-14	7a

Table 2: CO transitions targeted as part of FPG-3.

7.3 Results

In the following we show individual spectra and integrated intensity maps for all ObsIds. Note, that the data were pipelined using a **level 1 without OFF subtraction** algorithm, this in order to assess the pointing of the ON and OFF phase of the DBS raster scheme separately.

The individual spectra show baseline ripples with opposite phase as expected, the final DBS spectra (not shown here) therefore will have flat baselines. Because the spectral lines sit on top of the ripple at different phase, they do not match up perfectly in the spectrum maps.

Noteworthy is the non-detection of the CO 11-10 line and very weak detection of CO 6-5 in NML Tau. This latter observation was carried out immediately after the same line in o Ceti, which looks fine, so it is not expected that this observation suffers in any way from the aftermath of the SEU. In fact, the lines in NML Tau are expected to be considerably weaker and broader than in o Ceti, according to APEX results. **At this point it must be concluded that NML Tau is not suitable as a CO line pointing source for HIFI.** Note however, that NML Tau could be used to check pointing alignment in Band 7a, where the H_2O 3_{03} - 2_{12} 1721.3 GHz emission line is well detected in the same map (i.e. set up in the AOR to observe both possible lines).

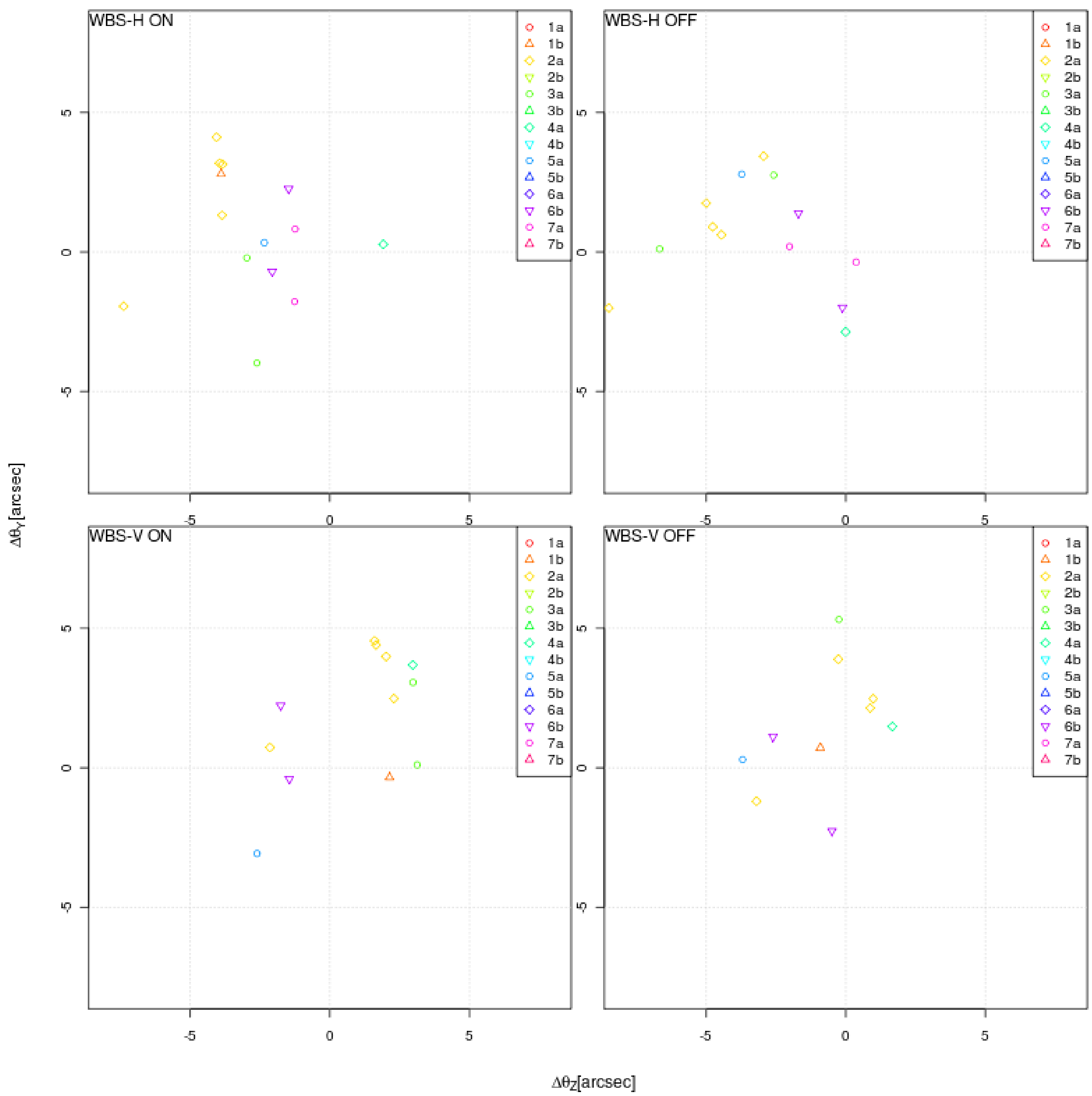


Figure 11: Observed and fitted focal plane offsets.

Figure 11 shows the fitted focal plane offsets colour coded by band. Note, that the measurements were all carried out using the SIAM entry for the synthesized HIFI beam in each band, which is an average of the beam positions of the H and V mixers.

7.4 Conclusions

In all pointing maps observed during PV-II, the central grid position always showed the strongest signal, i.e. all of these observations would have succeeded as single point observations. Based on these results there is at present no need to update the HIFI SIAM entries.

8. Spectral Performances

8.1 Intensity calibrations

The 12 m APEX telescope uses a number of AGB stars as standard sources for line calibration. In particular the results obtained by Risacher and van der Tak [1] for the CO 6-5 line at 691.4730763 GHz offers the opportunity to compare with HIFI results during PV-II.

8.1.1 Observations

Table 3 lists operational day and ObsId for those observations which were analysed for this report.

OD	ObsId	Source	Observation
264	1342190237	o Ceti	DBSRaster
264	1342190238	o Ceti	DBSRaster
264	1342190243	o Ceti	DBSRaster
266	1342190199	o Ceti	DBSRaster
264	1342190242	R Dor	DBSPoint
264	1342190240	IK Tau	DBSPoint
266	1342190200	IK Tau	DBSRaster
266	1342190196	W Hya	DBSPoint

Table 3: List of observations

8.1.2 Results

Table 3.2 lists observed peak intensities and line widths, obtained by fitting Gaussian profiles to the observed lines. Note, that the assumption of this type of profile is not necessarily justified, e.g. o Ceti shows signs of self-absorbed CO lines. However, it allows a standard procedure to be used for the derivation of quantitative values for the purpose of this report.

		HIFI					APEX	
		H		V				
Obsid	**Source**	**peak**	**width**	**peak**	**width**	**H/V**	**peak**	**width**
		[K]	*[km/s]*	*[K]*	*[km/s]*		*[K]*	*[km/s]*
1342190237	o Ceti	3.29	5.4	3.51	5.4	0.94	34.5	4.8
1342190238	o Ceti	3.28	5.4	3.51	5.4	0.93		
1342190243	o Ceti	3.23	5.6	3.51	5.6	0.92		
1342190199	o Ceti	3.32	5.5	3.52	5.5	0.94		
1342190242	R Dor	1.52	9.1	1.66	9.1	0.92	17.1	9.1
1342190240	IK Tau	0.36	24.8	0.49	24.8	0.73	6.6	24.2
1342190200	IK Tau	0.39	25.9	0.49	25.9	0.80		
1342190196	W Hya	0.88	11.4	0.91	11.4	0.97	?	?

Table 4: Observed line intensities and widths.

The beam width of the Herschel telescope at the frequency of the CO 6-5 transition is Θ_H = 32.7”, whereas the APEX telescope has a HPBW of Θ_A = 9.5” at this frequency.

Given a source size Θ_S, also in arcsecs, the expected intensity scaling between main beam brightness temperatures observed by APEX (I_A) and HIFI (I_H) can be expressed as

$$I_H = I_A * (\Theta_S^2 + \Theta_A^2)/(\Theta_S^2 + \Theta_H^2)$$

Solving for the source size we get

$$\Theta_S^2 = (\Theta_A^2 I_A - \Theta_H^2 I_H)/(I_H - I_A) \qquad \text{(Eq. 1)}$$

Figure 12 shows the expected intensity ratio as a function of source size.

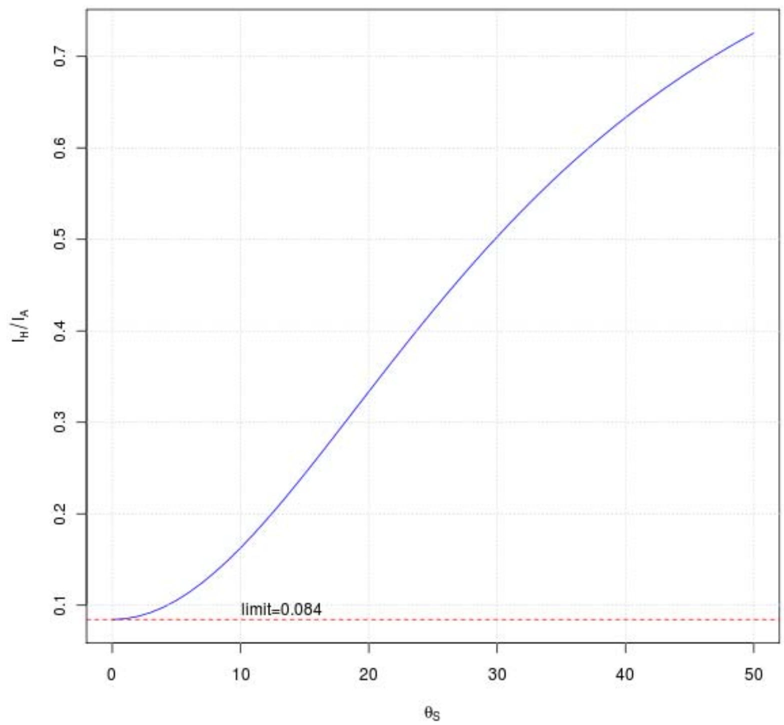


Figure 12: Expected ratio of HIFI to APEX main beam brightness as function of source size.

We use a main beam efficiency of η_{mb} = 0.74 to convert observed antenna temperatures for HIFI to a main beam brightness scale.

For o Ceti we get a source size of 4.1", corresponding to7.8*10^{15} cm at an assumed distance of 128 pc. For R Dor the size calculated according to Eq. 1 is 3.2", or 2.9*10^{15} cm at a distance of 61 pc. Finally, for IK Tau Eq. 1 does not produce a real-valued solution for Θ_S, because the ratio I_H/I_A is lower than the value of 0.084 predicted by Eq. 1 in the limit of vanishing source size (see Fig. 3.1). Note, that there is also a very deviating H/V ratio for this source in Table 3.2. However, comparison with the predicted spectrum in section 1.7 (last panel of Fig. 3.4) shows no obvious problem with the observed intensities.

8.2 Frequencies and Velocities

Summary

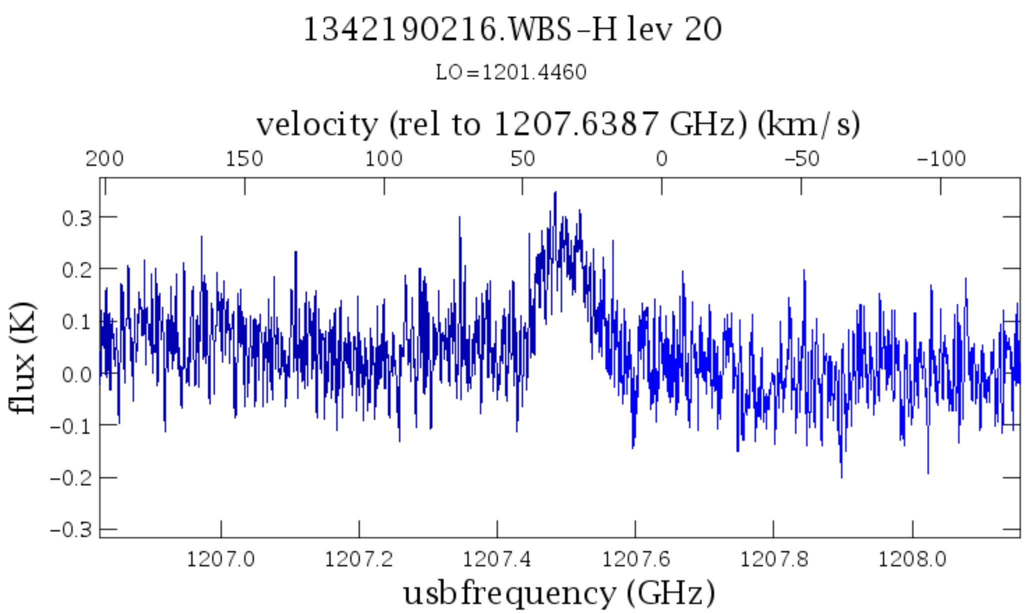
No serious problems have been found with the frequency and velocity calibration in the HIFI pipeline. There are some issues captured in SxRs which the user should be aware of when interpreting the frequency scales on level 2 spectra. Until these SxR are fixed they will cause an error in the frequency scale of up to 2km/s.

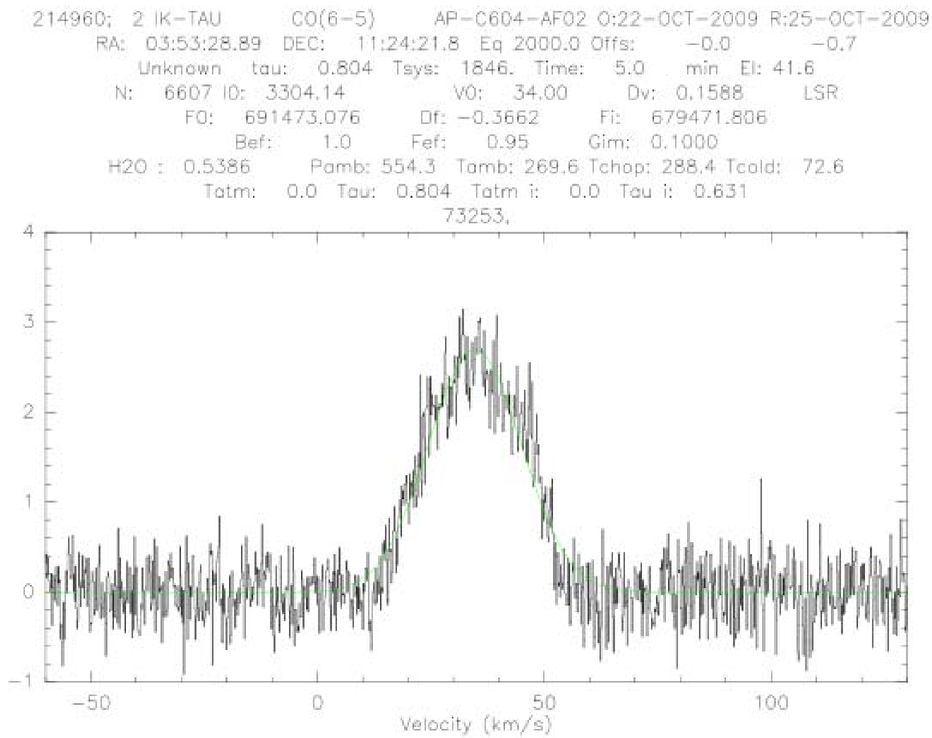
Outstanding Issues

- HCSS uses 19.5 km/s instead of 20.0 for lsr vel => < 0.5 km/s error, compared to the LSR frame used by the MPS. Additionally, the Sun is used instead of the SSBC => < 0.020 km/s error
- To compute the spacecraft velocity, HCSS uses an imprecise velocity of the earth with respect to the sun (and not the SSBC). This gives an error of ~< 1.5 km/s
- At present, the HIFI pipeline produces level2 spectra with frequency axis in the LSR frame, including Solar System Objects (SSOs). SSO spectra should be presented in their rest frame.

Absolute Frequency Consistency

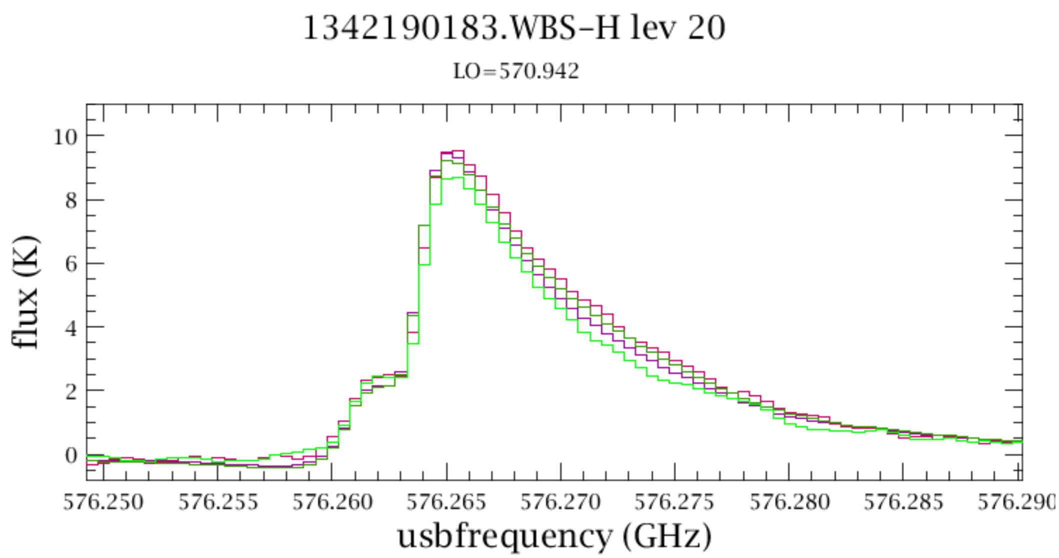
We compared the literature velocities for a set of HIFI detections, and in all cases found good agreement given the uncertainties (eg different species, data signal- o-noise). An example shown is CO 6-5 in IK Tau.





Multi-epoch Frequency Consistency

We compared observations of the same line and source at multipleepochs, and the detected line frequencies match. The longest check was for sourceLDN1157- B1, taken 186 days apart, and the motion of the spacecraft is correctly removedto an accuracy of better than 0.5 MHz (0.3km/s)



SSOs

Observations of Comet Wild-2 were checked against the predictions of the Horizons ephemeris. The Herschel-centric, Wild-2 apparent radial velocities were queried and interpolated to the time of observation.

The Level2 frequency axis is affected by the SPRs above; but within HIPE I can easily use Horizons to predict the IF frequency of detection, using my own spacecraft ephemeris (H20090622_0001.LOE). I find the water lines within at most 0.5 MHz of the predicted frequency. See table. Whether the differences between HRS and WBS are significant is still being investigated.

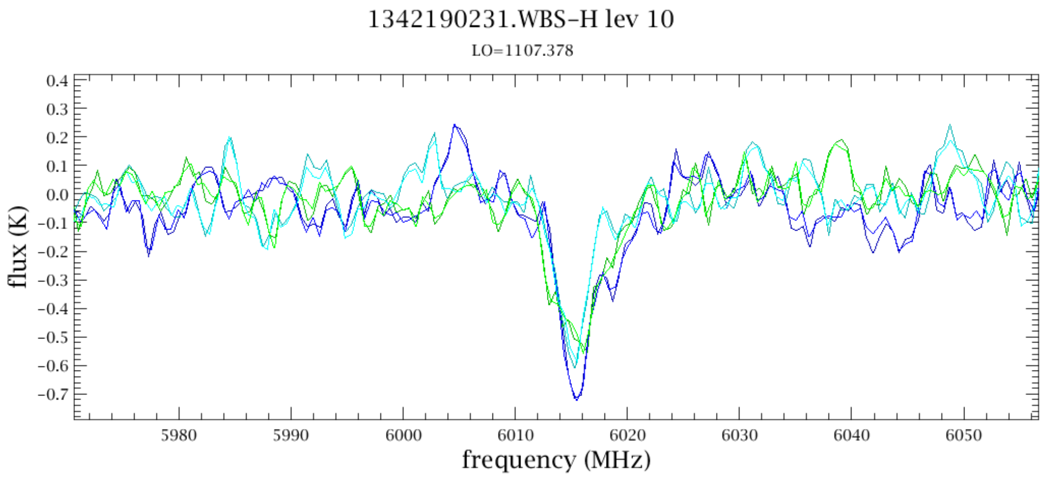
H20 1(1,0)-1(0,1) 556936.00 MHz

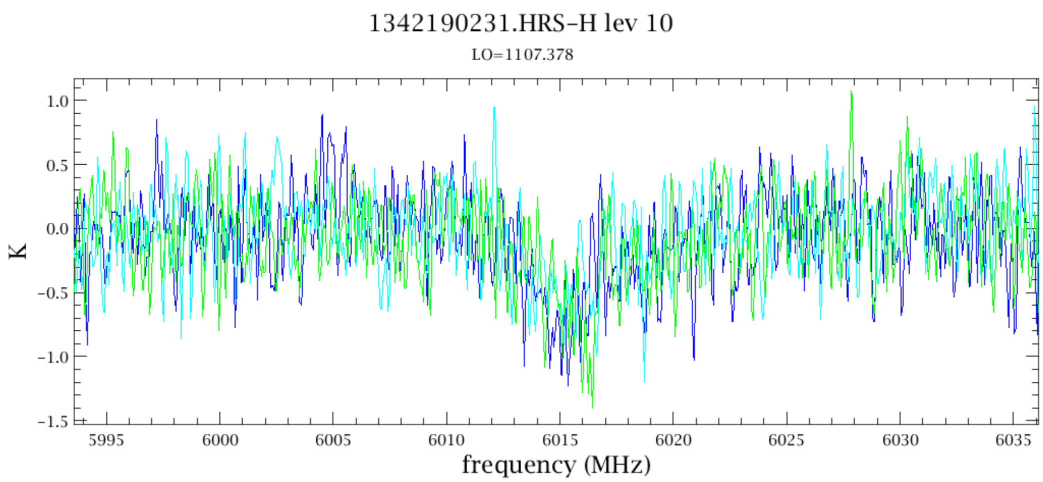
Backend	pred-detect (IF)(MHz)
WBS-H	-0.07
WBS-V	0.03
HRS-H	0.33
HRS-V	0.33

H20 1(1,1)-0(0,0) 1113342.96 MHz

Backend	pred-detect (IF)(MHz)
WBS-H	0.11
WBS-V	0.41
HRS-H	0.51
HRS-V	0.51

Example Wild-2 spectra (level1) are below. Note that the negative amplitudes are a result of the ON an OFF phases being out of synchronization in the pipeline after timing-related command completion errors in the FastDBSCross mode. This error has been fixed and verified. The level2 frequency scale below is in the LSR frame.





Velocities in the HIFI Observation Context

For the interest of the user, here is summary of the several volcities one can find in the metadata and data in the Observation Context. This discusssion applies to HCSS 2.0.1453. They will change in the near future.

- obscon.meta['radialVelocity'] : opposite of V_lsr.
  This is the velocity of the spacecraft, as seen by an observer at rest in the LSR, in the direction of the target. I don't think it's used for anything, rather (c) below is used in computation.
- htp.meta['vlsr'] :the user-entered redshift from HSPOT.

This is used in setting the LO so that the desired line is in the band, but has no other explicit role in the pipeline at present. In the near future it will be used to transform spectra to the rest frame of the target.

- dataset['velocity'] column: same as a, but for the particular time and pointing of the spectrum.

9. IF Spectrum Repeatability (Sideband Line Ratios)

Specific tests have been carried out in the laboratory and on-orbit since the first checkout phase and again during CoP-II and PV-II, to assess the repeatability of spectral lines occurring at different IF frequencies in both upper and lower sidebands. On orbit these tests have been done so far in beam splitter Bands 1b, 2a, and 5a, and diplexer Band 4a, towards NGC7538 IRS 1 using the strong CO lines. The frequency was gradually changed so the line was stepped across the band to look for changes in intensity. Figure 13 shows how this looks in the Band 1b engineering test, with all 15 spectra of the same CO 5-4 line over-plotted in IF frequency in the upper sideband of the WBS-V. Figure 14 shows a similar example, taken from a different source using a standard Spectral Scan in 1b on the H_2O 1_{10} – 1_{01} 557 GHz line.

All of the tests were done in DBS mode. The line signal is typically 10-20K and noise less than 0.2K, resulting in a S/N ratio of over 100.

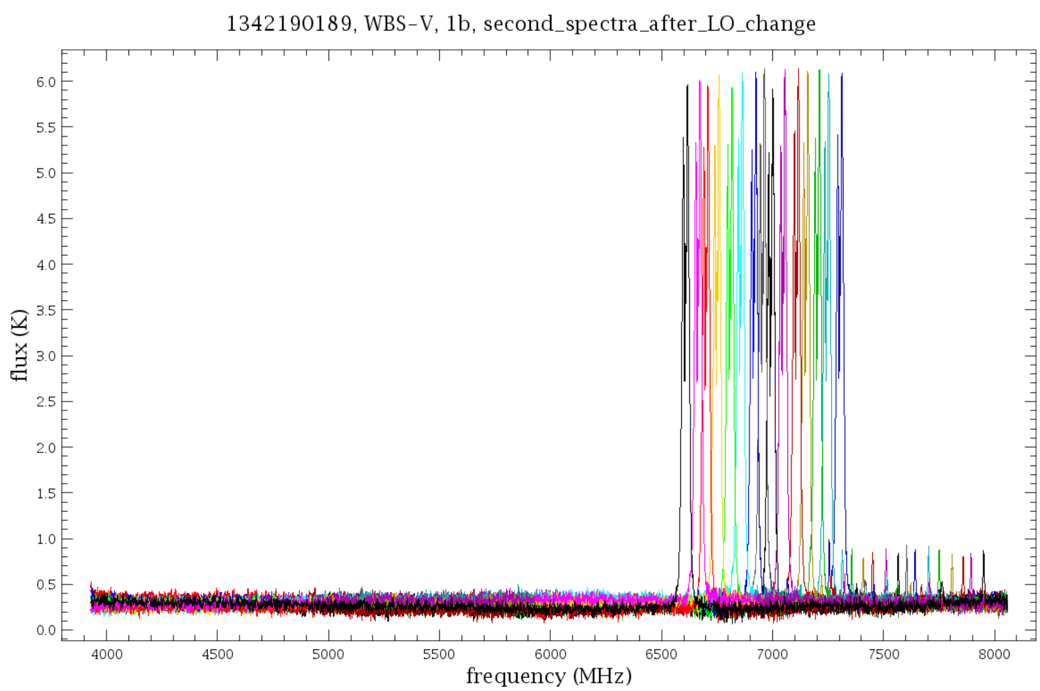


Figure 13: CO 5-4 with WBS-V, spaced across the upper sideband from an engineering Spectral Scan.

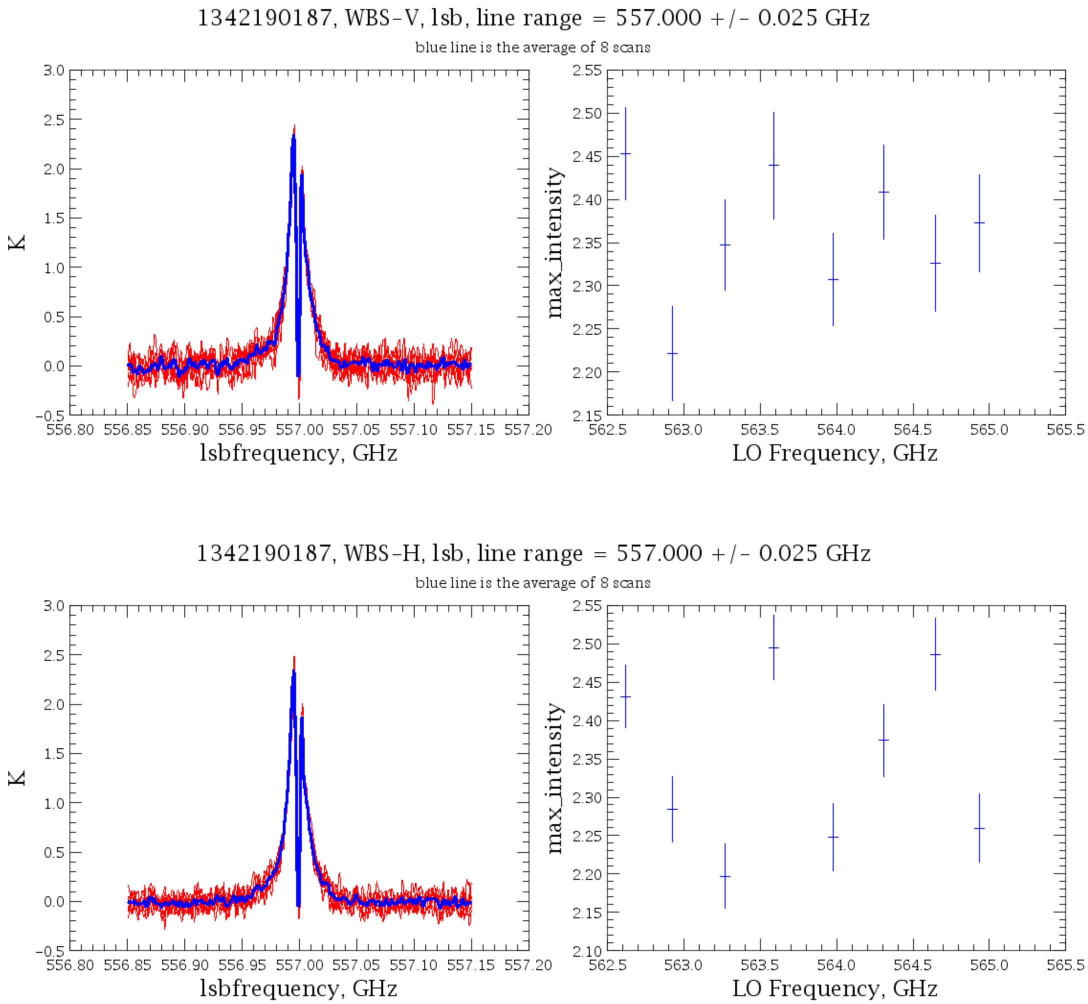


Figure 14: Measurements of the 557 GHz water line at 8 positions in the LSB in WBS-V (upper) and WBS-H (lower).

While the comparison between flight data and ground-based gas cell measurements is ongoing, the following conclusions are reached for the bands without diplexers:

- **Band 2a**: the integrated line intensities vary by less than 1% around the average value.
- **Band 5a**: there is a slight USB/LSB line strength difference (3%). This is true for both polarizations. The (H-V)/H intensity difference is also 3% on average; true for both sidebands. This could be due to pointing offsets between the polarizations.
- **Band 1b**: similar to Band 2a.

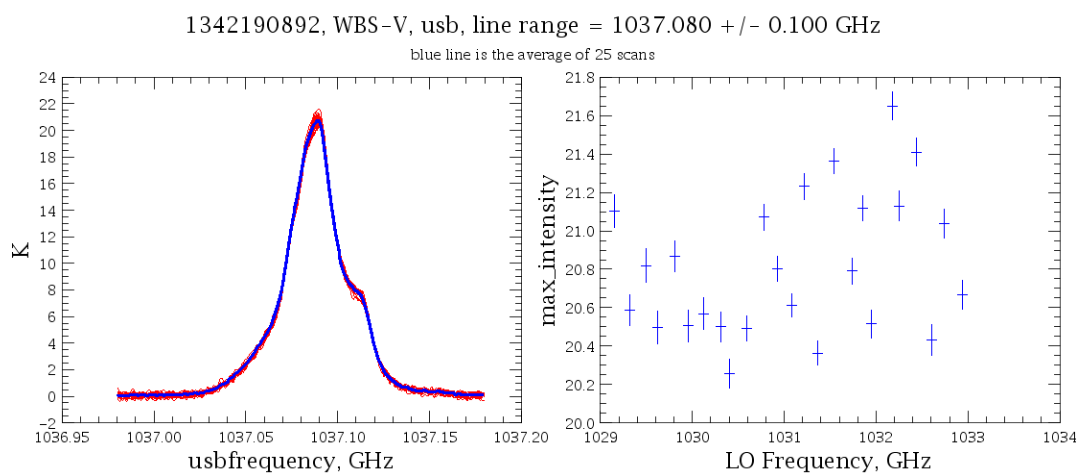
For **Band 4a**, the only diplexer band tested so far, the SBR test was carried out without retuning the diplexer, and then the same test was redone but with retuning. The conclusions are reached:

1. The observations *without* diplexer retuning show that in the unlikely event of a diplexer mistune, the diplexer window significantly affects calibration. At least some of this variation can be eliminated by recalibrating with the ratio of the noise levels at the frequency for which the diplexer is correctly tuned. This should not happen for normal observing.

2. The Standing Wave test showed no convincing effect -- the variation is less than \pm 2% and this slight variation does not show a 650MHz period like the diplexer standing wave.

3. With the diplexer retune, and only taking into account the scans preceding the sharp increase in noise level, the CO 9-8 line seen in the LSB is a few percent weaker than in the USB. It remains to be seen if this is a real SBR effect or rather due to the diplexer. All of the variations seen are greater than identical spectra affected only by random noise at the RMS noise level.

4. The V polarization is systematically stronger than the H but the line profiles are different (see Figure 15), suggesting that at least part of the difference is due to a pointing offset.



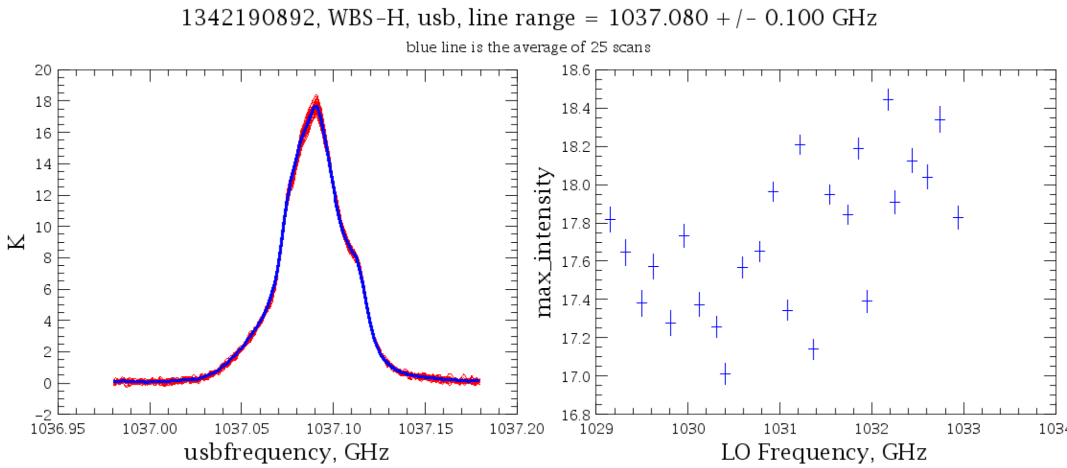


Figure 15: Measurements of the 1037 GHz CO 9-8 line at 25 positions in the USB in WBS-V (upper) and WBS-H (lower).

5. The RMS noise was much greater when the CO line was in the LSB (high LO frequency) and this was true for both polarizations.

A summary of these results is represented in Figure 16.

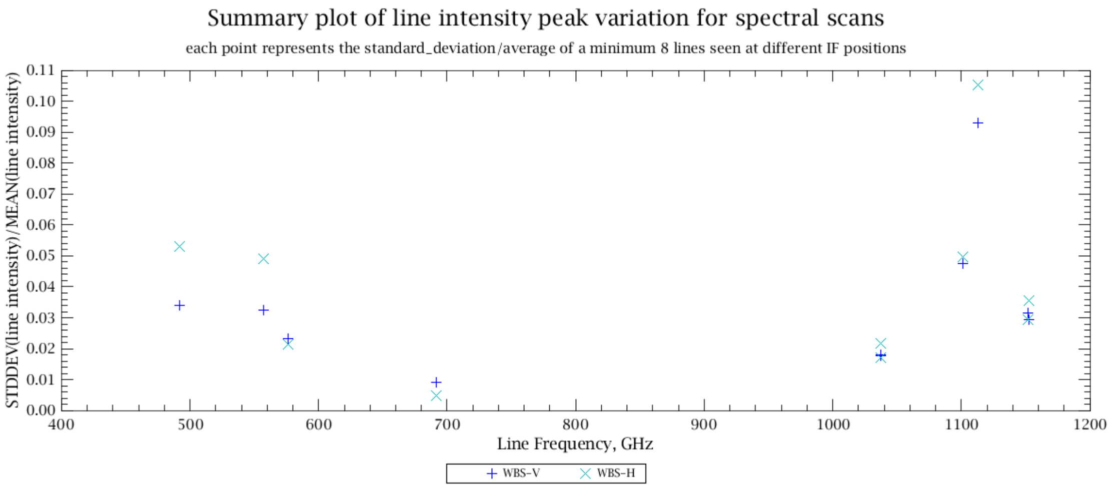


Figure 16: Peak intensity variation of spectral lines as measured at 8 or more positions in the IF, from PV-II Spectral Scans.

10. Spurious Responses in HIFI

HIFI, like all heterodyne receivers, suffers from spurious response. These 'spurs' can significantly degrade the quality of spectra, and therefore it has been prudent to track and catalog these features in all HIFI data taken since pre-launch. This catalog has been implemented in HSPOT so users can be warned if they tune the LO near the position of known spurs.

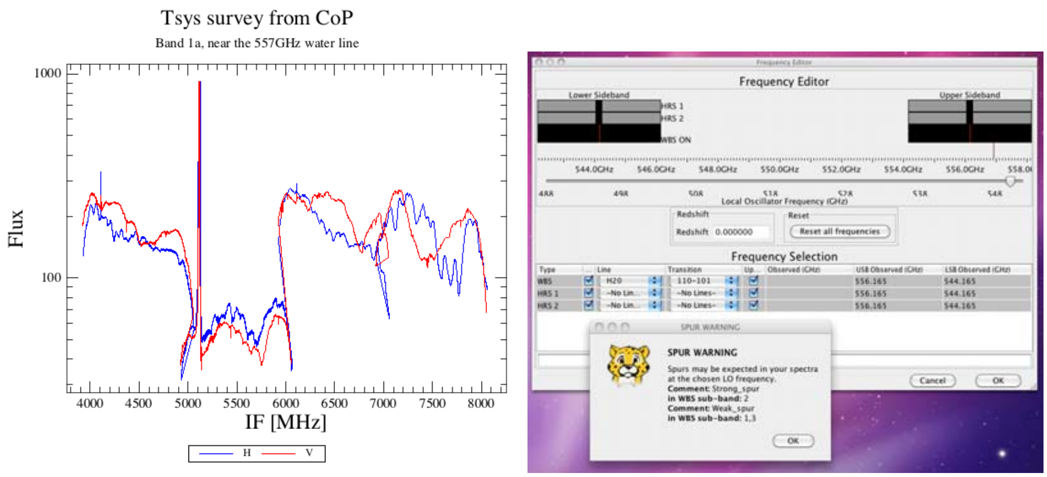


Figure 17: On the left is the spectrum from the CoP Tsys survey related to the HSPOT AOT on the right. Weak spurs are seen in the first and third WBS subband, and a strong spur, which in addition to saturating the detector, suppresses the flux from the entire subband. In the HSPOT window, the user placed the desired water line in the third subband of the upper sideband, and the system generated a warning. In this particular case, the weak spur poses no threat to the line.

10.1 Analysis of spurious responses in WBS

In general spur positions and strengths have remained similar between the prime and redundant sides, and across over a year of data acquisition stretching back to pre-launch test activities.

The spurs that cause the most concern are the ones near important water lines.

10.2 Spurs in Band 1a

In 1a, a strong spur exists blueward of 548.7 GHz. This spur is very strong, saturating the detector and rendering the entire 4GHz passband unusable. This is unfortunate, as it directly impacts observations of the 557 GHz water line. There are very narrow (~500MHz) regions in LO tunings where the spur seems well behaved and one could in principal take a relatively clean spectrum. However it is not clear how stable this ‘safe zone’ is over time. We recommend that users try to use the lower sideband of band 1b if possible.
Note that engineering tests in PV revealed that it may be possible to remove the spur by making slight changes to bias settings on the receiver. This will be tested, and if successful, we can modify our recommendations for this band.

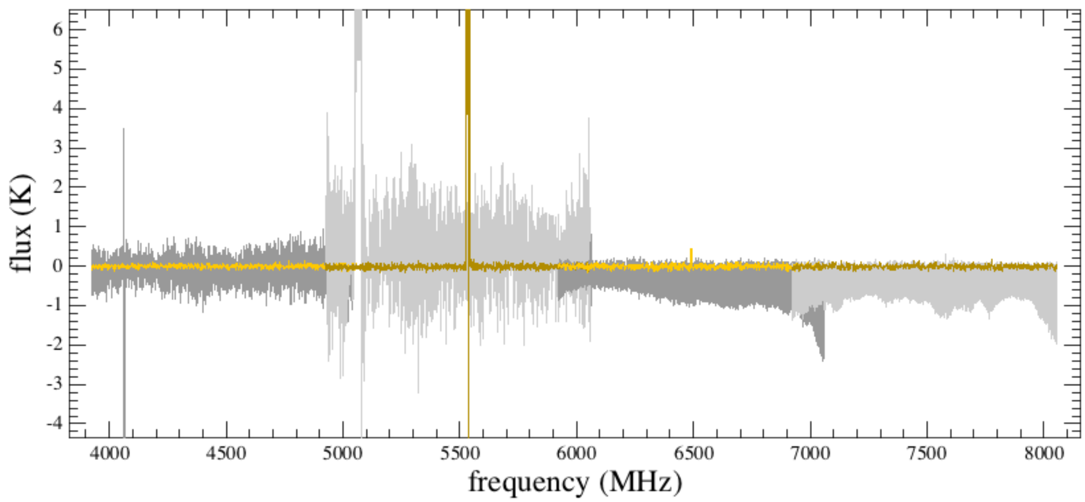


Figure 18: Spectra taken from 2 different LO tunings in 1a. The grey plot is from a tuning of 549.3 GHz and the spur wipes out not only the subband in which it resides (2), but the entire spectra due to the crosstalk. At 550.4 GHz however (yellow trace), the spectrum is well behaved aside from the spur in the second subband.

10.3 Spurs in Band 4b

Water at 1113 GHz is potentially corrupted by a spur that appears between LO tunings of 1090 GHz and 1108 GHz. However unlike the 1a spur, this one is very weak and sometimes disappears altogether, likely due to changes in instrument temperature.

It is still recommended to place this spur in a subband different from that of the water line. The position of the spur in the IF as a function of LO is fit well by the following formula:

$$\mathrm{IF} = 5064.9 - 44.3x - 0.6x^2$$

where $x = LO - 1090.498$ GHz

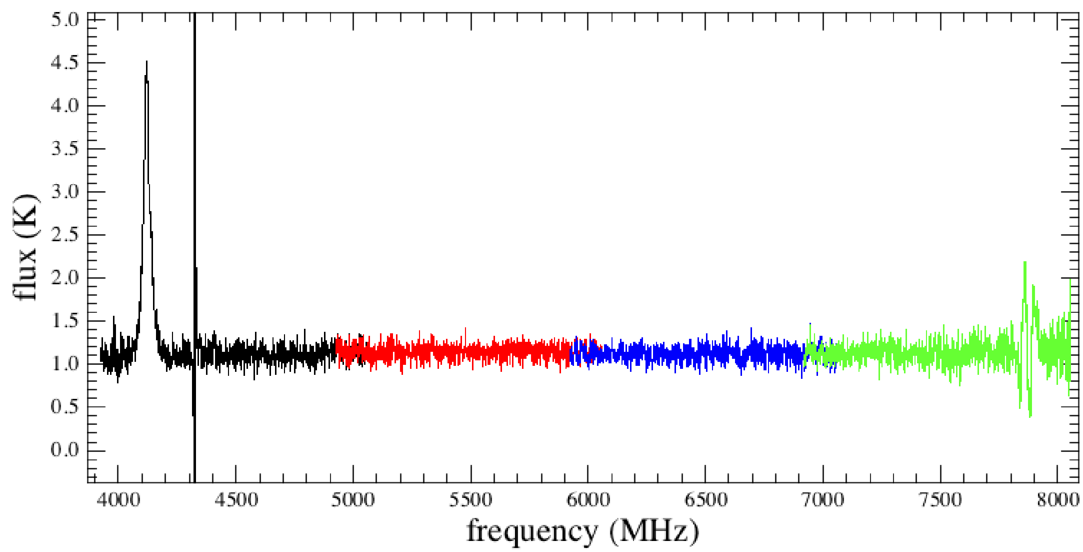


Figure 19: Though band 4b spurs are strong compared to real lines, they are very narrow and do not seem to affect the integrity of the spectra around them. This spectra was taken during PV at an LO setting of 1105.6 GHz.

10.4 Spurs across other bands

A detailed analysis of spurs is ongoing based on observations taken in PV. A summary of the table that HSPOT uses is provided here. Users who need LO tunings in any of the affected ranges are encouraged to contact the helpdesk(s) for advice.

Note that the ranges could be as much as 2GHz wider on each side of a spur due to the resolution of the surveys from which these were determined.

- **Band 1a**: Strong spur above 548.7 GHz.
- **Band 1b**: No spur activity.
- **Band 2a**: Spurs at 700.0 GHz, and 712.0-718.0 GHz.
- **Band 2b**: Spurs at 772.0 GHz, and 776.0-788.0 GHz.
- **Band 3a**: Spur at 823.0 GHz.
- **Band 3b**: Spurs between 868.0 – 876.0 GHz, and 952.0-954.0 GHz.
- **Band 4a**: Spur at 967.0 GHz, and 1001.0-1003.0 GHz, and 1017.0 GHz.
- **Band 4b**: Spur between 1090-1108 GHz.
- **Band 5a**: Spurs between 1232.0-1240.0 GHz
- **Band 5b**: Spurs between 1232.0-1236.0 GHz, 1258.0-1272.0 GHz.
- **Band 6a**: Spur at 1544.0 GHz
- **Band 6b/7a/7b**: No conclusions yet.

10.5 Spurious response in HRS

Spurs in WBS do not correspond to spurs in HRS. While the investigation of HRS spurs has not yet been as detailed as in WBS, it is already clear that the spur in 1a for instance does not impact the HRS at all. Because spurs are found generally in spectral surveys, and since spectral surveys generally do not have HRS data, a full catalog of HRS spurs has been slower to generate.

10.6 Treating spurs in software

Spurs are automatically flagged during pipeline processing, and ignored in subsequent processing. For moderate spurs, this is generally sufficient. Strong spurs however, which corrupt entire subbands or spectra, require an extra step of cleaning.
This is easy to do in software, and we have had excellent success in cleaning up spectral scans for use by the deconvolution.

11. HIFI intensity calibration budget

The following table summarizes the relevant parameters and effects and our current knowledge and strategy.

Parameter	Status	Strategy	Next action
Beam efficiencies	Parameters known based on theoretical modelling; preliminary values derived from Saturn observations; accuray 5-10%	Use theoretical values until measured	Observations in April 2010 on Mars
Coupling coefficients	Measured in ILT, no further change expected; accuracy 3-5%	Leave as is	
Chopper position HBB/CBB		Treat as error	
Standing waves towards calibration loads		Treat as error	Can be modelled?
Sideband ratio	Analysis of gas-cell measurements from ILT; accuracy is a few percent for beam-splitter bands, up to 20% for diplexer bands.		Diplexer modelling
Standing waves	HEB IF standing wave analysis ongoing, effect on accuracy TBD		Tests during PV-II
Continuum linearity			
Line linearity	Negligible error		
Pointing	first FPG-3 done during PV	Continue to monitor	Dedicated observations in April 2010 on Mars
Spurs	Inventory of spurs available, Hspot assists with avoiding		dedicated program for spurs in selected

	most critical frequency areas		bands
IF feedback	Expected to be mostly negligible	treat as error until sufficient data available to allow correction	evaluate measurements done in PV-II