# Cycle38 Frequency Calibration Tests

Version 1.0 of 2011-05-11, by Ian Avruch


## Abstract

Analysis of cycle38 frequency calibration test observations indicates the COMB calibration is accurate to 100kHz (worst case), V-CCD4 is still properly calibrated (as of cycle38), and the current pipeline handling of the HRSxWBS freq calibration leaves errors of 450kHz, in the worst case.



Technical Note: HIFI-ICC-TN-2015-002

13 pages

# Introduction

In cycle38 we performed a set of test observations related to frequency calibration:

A. target Ep Aqr, purpose: Can an unresolved line be used to calibrate WBS spectral resolution?
   1342219260 Aot3_P_DBSNoC_1b_CO5-4_EpAqr_FCal_cycle38
   1342219261 Aot3_P_DBSNoC_1b_CO5-4_EpAqr_cycle38_H74

B. target G34.3+0.1, purpose: Are there noticeable differences between the COMB and FCAL frequency calibrations on this crowded spectrum?
   1342219184 Aot3_P_DBS_1a_G34.3+0.1_hrsWIDE_Fcal_cycle38
   1342219185 Aot3_P_DBS_1a_G34.3+0.1_hrsWIDE_cycle38_H74

C. target NGC7023 CO(5-4), purpose: Create a fake "COMB" by scanning a narrow line across the IF, look at freq cal self-consistency.
   1342219264 Aot3_S_DBS_1b_CO_5_4_NGC7023_Fcal_cycle38
   1342219265 Aot3_S_DBS_1b_CO_5_4_NGC7023_cycle38_H74

D. target NGC7023 CII, purpose: Check that HRS operates properly in FCAL modes.
   1342219320 Aot3_P_DBSfast_7b_CII_NGC7023_hrsHI_Fcal_cycle38
   1342219321 Aot3_P_DBSfast_7b_CII_NGC7023_hrsHI_cycle38_H74
   1342219322 Aot3_P_DBSfast_7b_CII_NGC7023_hrsOFF_Fcal_cycle38
   1342219323 Aot3_P_DBSfast_7b_CII_NGC7023_hrsNOM_Fcal_cycle38
   1342219324 Aot3_P_DBSfast_7b_CII_NGC7023_hrsLO_Fcal_cycle38
   1342219325 Aot3_P_DBSfast_7b_CII_NGC7023_hrsWI_Fcal_cycle38

# Analysis

Subsection headings refer to the entries in the Introduction.

## 0.1 A: Ep Aqr Unresolved Line

None yet.

## 0.2 B: G34.3+0.1 Crowded Spectrum

There was a difference between the two but not due to frequency calibration. Rather the mixer current wasn't settled during the first of two HC measurements in 1342219184, so the interpolated bandpass correction was inappropriate and left a frequency-dependent amplitude error compared to 1342219185. Christophe confirmed this by overwriting the first HC in 1342219184 with the second and reprocessing, showing improvement. This problem is reported in SPR HIFI-4190.
Figure 5 shows, in light blue, the difference spectra between the standard COMB frequency calibration and the FCAL mode. The lack of features in light blue indicates the spectral lines subtracted well, hence reasonable frequency calibration using FCAL mode.

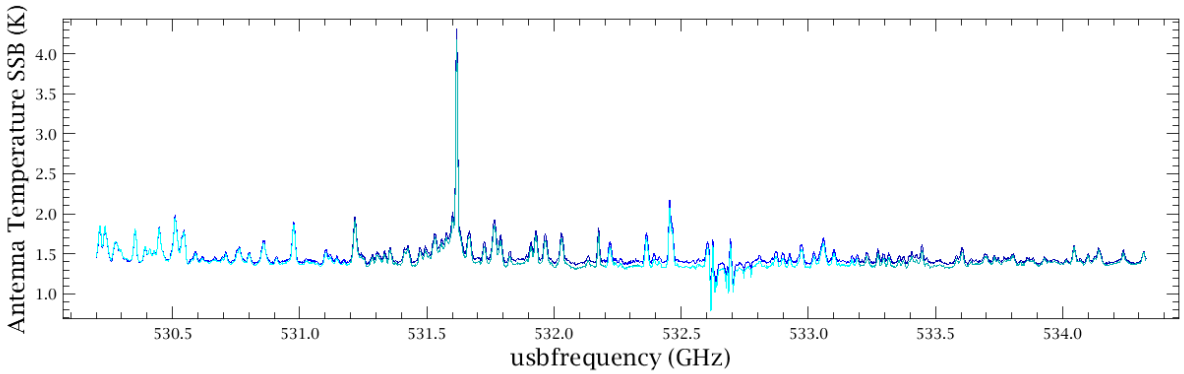


Figure 1: Test (B): obsids 1342219184 & 1342219185 WBS-H Level2 overplotted. Note the slight difference in baseline level.

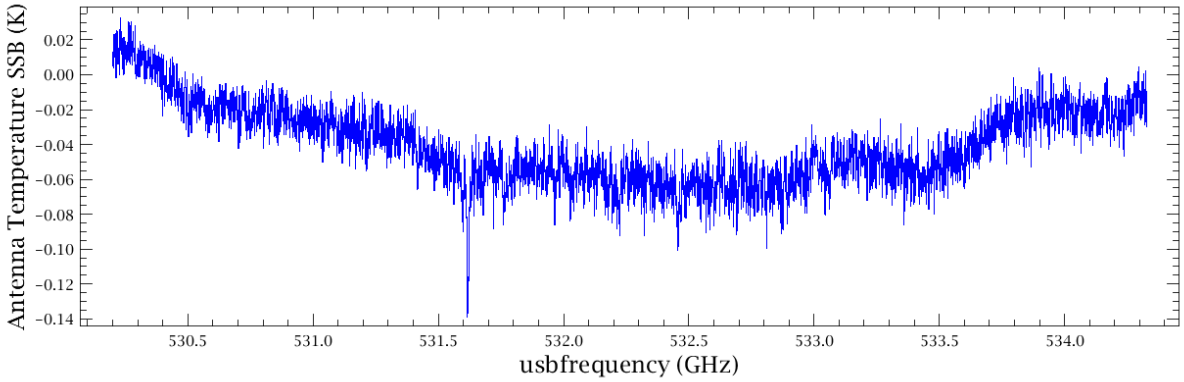


Figure 2: Test (B): obsids 1342219184 & 1342219185 WBS-H Level2 difference spectrum.

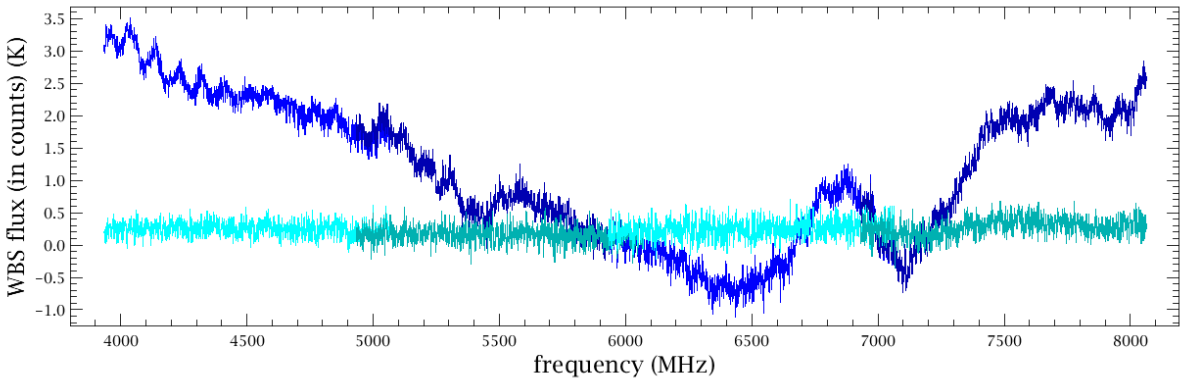


Figure 3: Test (B): Dark blue is the difference between the two $T_{sys}$ measurements in 1342219184. The residual shape accounts for the shape in the difference spectrum. Light blue is the $T_{sys}$ difference in 1342219185, just a total power offset.

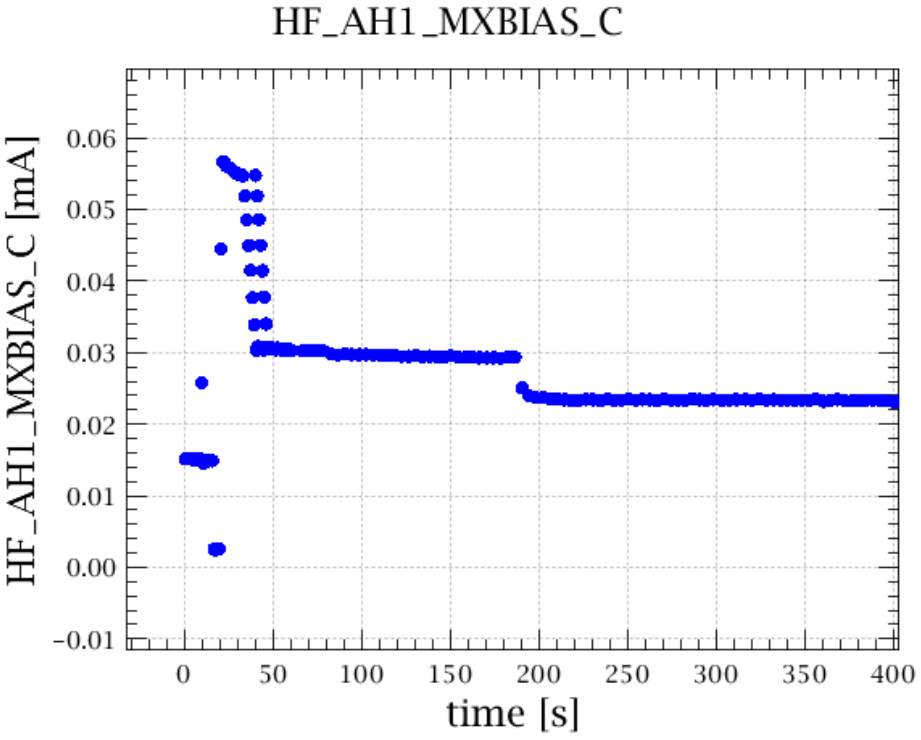


Figure 4: Test (B): mixer current relaxation during 1342219184

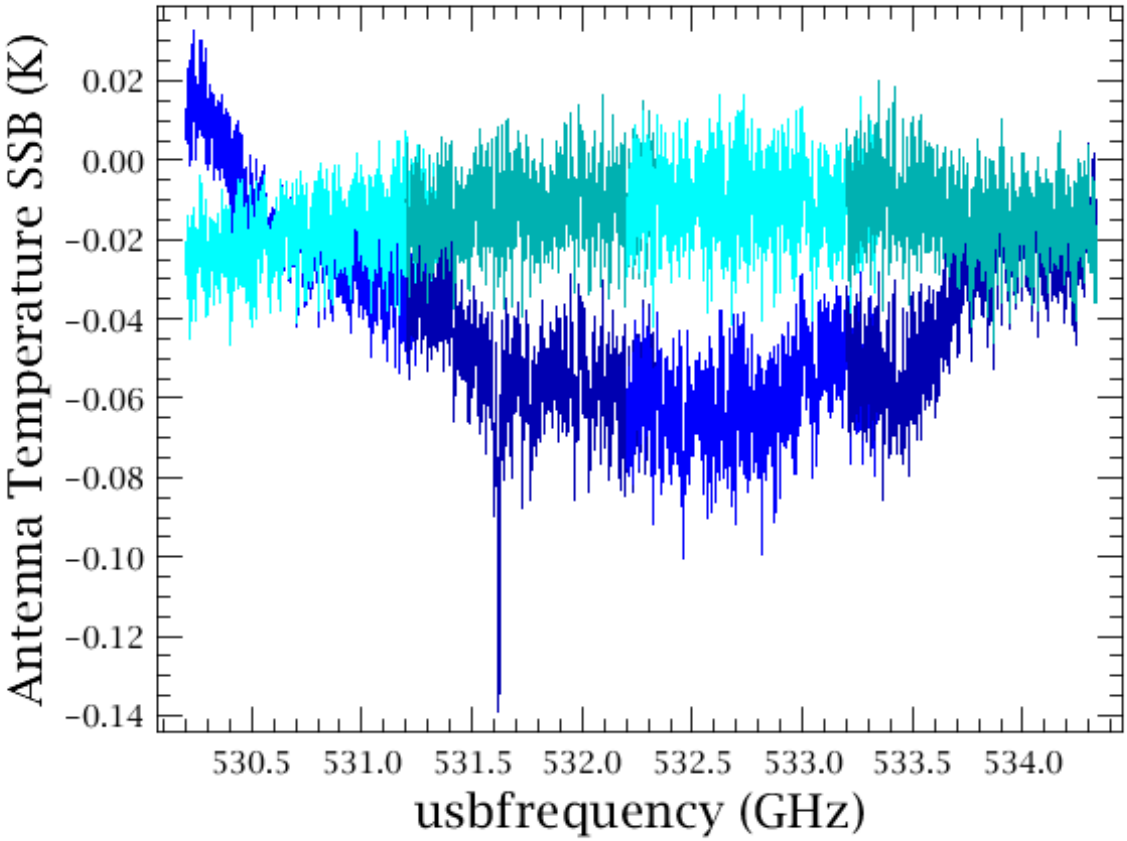


Figure 5: Test (B): difference spectra (1342219184-1342219185) using both 1342219184 HCs (dark blue) and only 2nd HC (light blue). The lack of features in light blue indicates the spectral lines subtracted well, hence reasonable frequency calibration using FCAL observing mode.

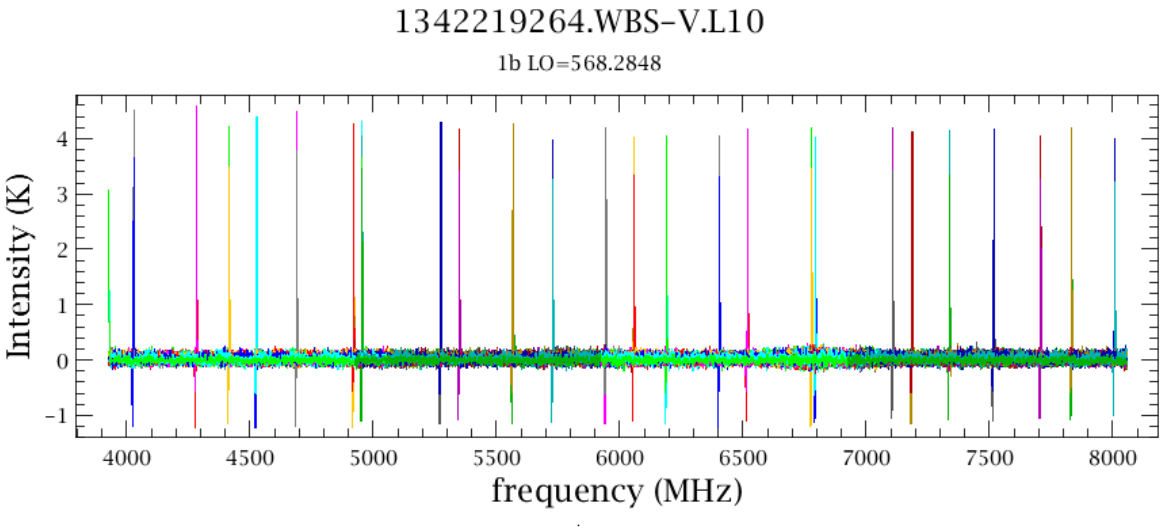


Figure 6: Test (C): All the Level1 WBS-V science spectra in obsid `1342219184`; 25 useful LO settings. Because the two OFF phases of the DBS chopped into different emission, the two phases are analyzed separately.

## 0.3 C: 'Fake' COMB

A spectral scan observation on a narrow line was repeated in standard and FCAL modes. There were 26 LO settings, 25 of which caught the line fully within the IF. Each LO setting has an associated COMB measurement. Observation 1342219265 is frequency-calibrated using the instrumental COMB. Observation 1342219264 is calibrated with the HRSxWBS correlation algorithm implemented in the pipeline for FCAL mode. The idea is to compare the measured IF shift of the line (by fitting the two spectra) with the LO change. Are they consistent? And how does the HRSxWBS freq cal deviate from the COMB cal? We expect higher residuals because of uncorrected nonlinearity in the CCD pixel-to-frequency transform. Bear in mind that a nominal, unchanging polynomial is currently applied.
The LOs at Level1 (column 'LoFrequency') are already Doppler-shifted, which is convenient for this analysis. It amounts to a $\approx 5.2$ kHz difference over the observation time range which would otherwise need to be accounted for.
The shift-fitting procedure is, I take one line from one LO setting as a model (cubic-spline-interpolated for a smooth curve) and fit it to all other lines. I do this for all pairs, *ie* I fit for the shift between LO setting $i$ and setting $j$, and later between $j$ and $i$. The redundancy allows me to check that the line-shift fitting results make sense in that the shift of line $i$ to line $j$ is the equal and opposite of $j$ to $i$, which I do find to be the case (see Figure 10). The result, in short, is that the frequency calibrations at different LO settings show residual frequency errors at a level of less than 100 kHz (the measured shift between lines in the IF is always within 100 kHz of that expected from the LO change), for the COMB calibration. The median absolute residual among H,V, both DBS phases is about 50 kHz. The worst found was 100.5 kHz . This is consistent with the stated acuracy of the COMB procedure.

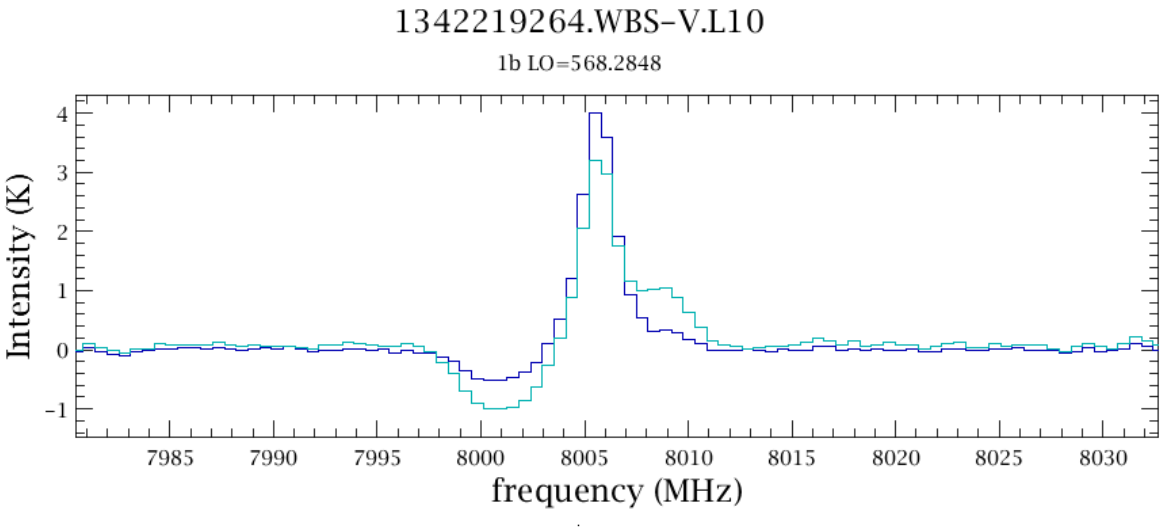


Figure 7: Test (C): Zoom on one IF line in 6. The two DBS phases (dark blue and light blue) have different line profiles, so are treated separately. The sharp lineshapes are good for fitting.

An interesting question is whether WBS-V CCD4, with its diminished laser power, is detectably different in frequency calibration from the other CCDs. A K-S test on the residuals from fitting only the intra-CCD LO shifts shows that the residuals from CCD4 are consistent with being drawn from the same distribution as the other CCDs. I tested all pairs of CCDs; Table 1 presents K-S test results for obsid `1342219265` WBS-V DBS-phase 2.

| CCD pair | K-S D value | K-S P value |
|---|---|---|
| 1,2 | 0.333 | 0.6309 |
| 1,3 | 0.433 | 0.1535 |
| 1,4 | 0.419 | 0.0662 |
| 2,3 | 0.267 | 0.9086 |
| 2,4 | 0.381 | 0.4094 |
| 3,4 | 0.238 | 0.7790 |

Table 1: Test (b): K-S test on frequency calibration residuals among WBS-V CCDs. CCD4 does **not** stand out as a poor performer.

The same analysis on `1342219264`, the FCAL obsid, produced these results: the answer is that calibrated frequencies are wrong by up to 450kHz, worst case. Median differences were about 300kHz. This is our first estimate of the deficiency of the current HRSxWBS frequency calibration scheme, which solves for the constant in the pixel-to-frequency polynomial but assumes nominal values for the necessary higher order terms.
On the one hand we have to do better, but on the other we're not so very bad at present. I doubt anybody would notice a 500kHz shift of a line centroid! *Note added: opinion among*

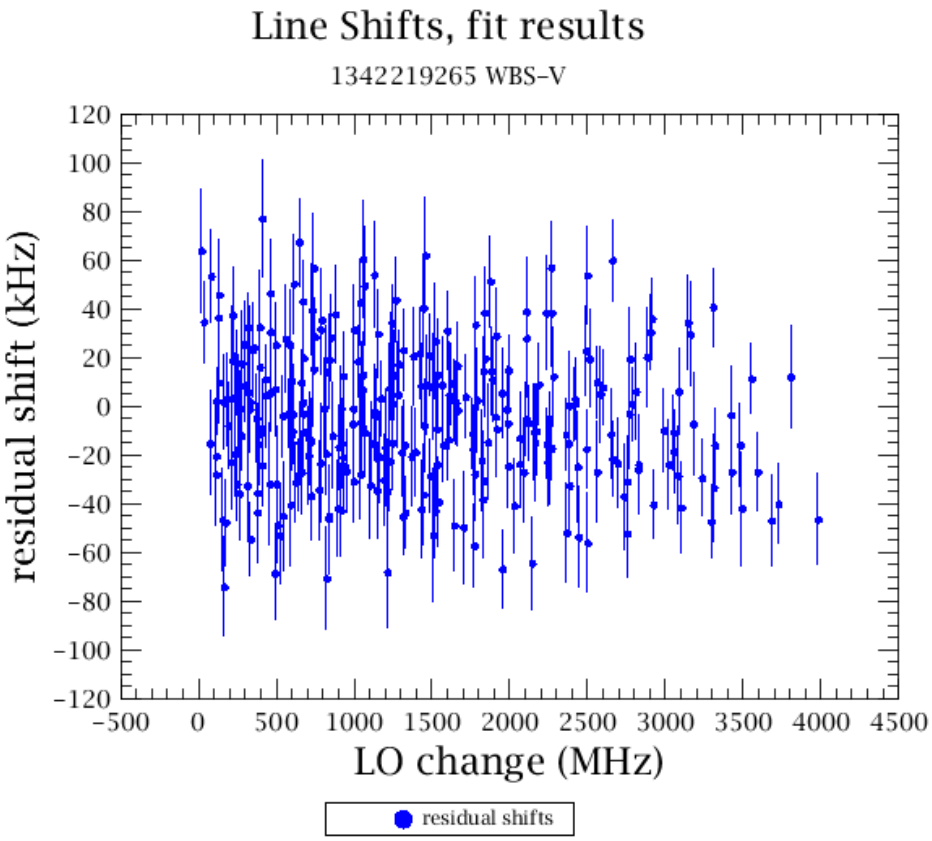


Figure 8: Test (C): Fit results for COMB calibration, WBS-V DBS-phase 2. The y-axis is (Fitted line shift) - (LO change). All LO differences (all CCDs together) are shown. No remarkable trend (good!). Mean value is 0 within uncertainty

*the HIFI ICC core is that 500 kHz is too large an error to allow in the pipeline*
The interpretation of the results in Figure 11 is that there is a residual error in the WBS frequency calibration of each CCD; the nonlinearity within each CCD is not entirely corrected. No single CCD is appreciably worse than another. This is an expected deficieny of the current HRSxWBS calibration routine.
It is also nice to see there is no IF-scale trend in either procedure (COMB or HRSxWBS), not that one is expected.

## 0.4 D: HRS in FCAL modes

I have only done a visual check so far, and it seems all HRS settings worked OK, all data expected are present, and the frequency calibration is consistent among all obsids. I haven't done a fit for shifts among the obsids yet, which would be another interesting number on the reproducibility of the HRSxWBS freq cal.

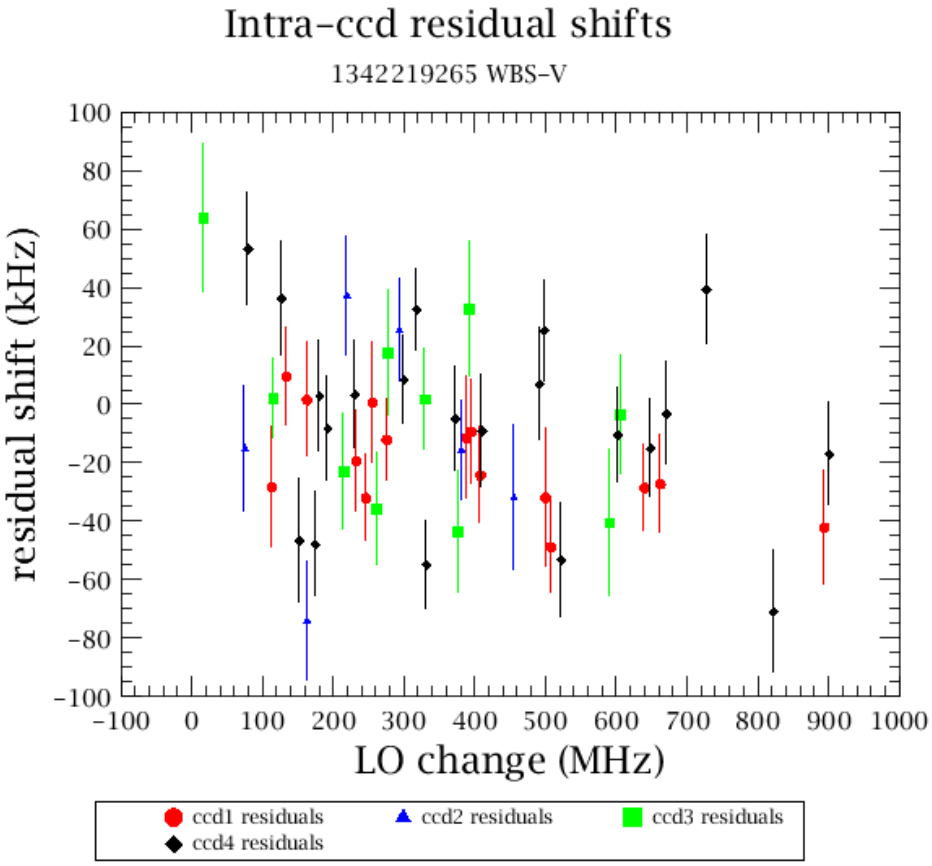


Figure 9: Test (C): Fit results for COMB calibration, WBS-V DBS-phase 2, only differences within single CCDs. The y-axis is (Fitted line shift) - (LO change). Although CCD4 frequency calibration performance might appear to be the worst of the four, a K-S test indicates no significant difference (see Table 1)

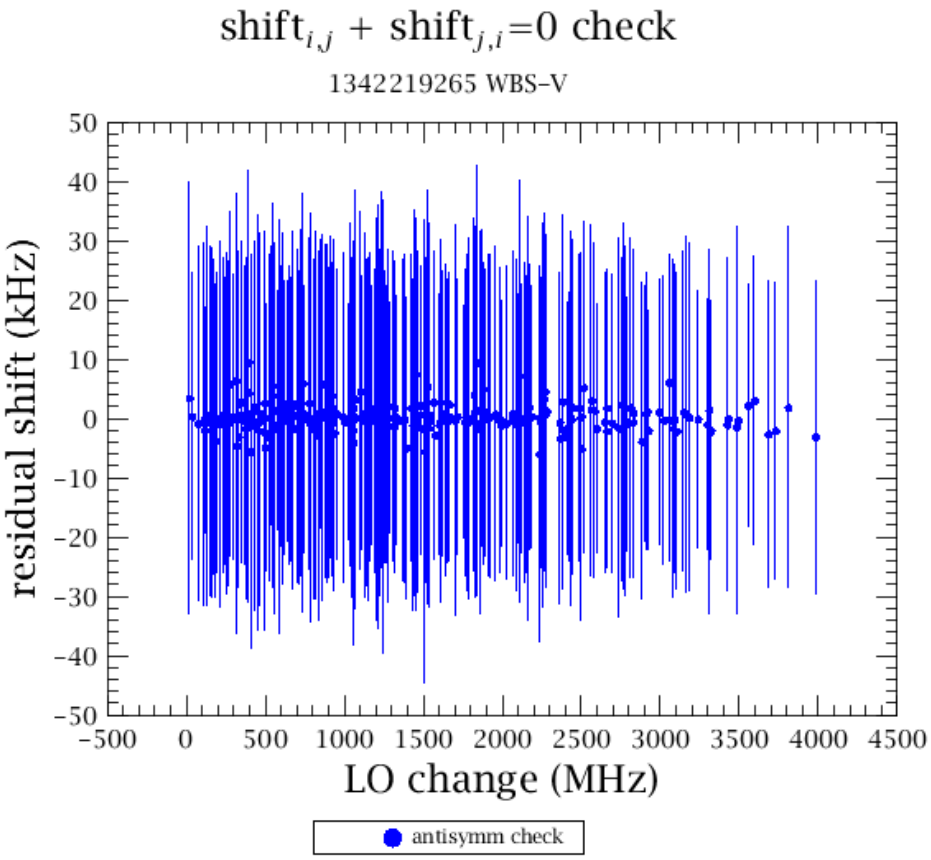


Figure 10: Test (C): A check on the consistency of the fits and error bars on shifted spectral lines: the shift of line $i$ to $j$ plus the shift of $j$ to $i$ should be zero. From this figure it appears my fitting accuracy is $\lesssim$ 10 kHz

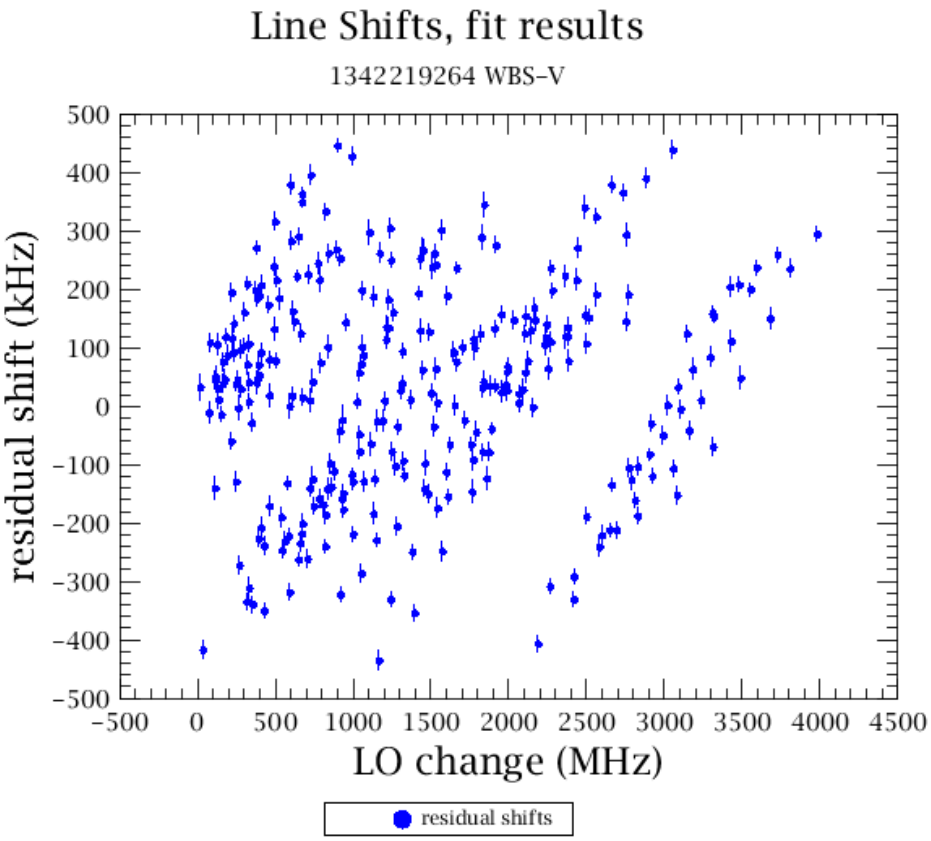


Figure 11: Test (C): HRSxWBS FCAL frequency calibration errors for LO pairs across the whole IF (obsid `1342219264`, WBS-V). The groupings corresponds CCD pairs, *eg.* the largest LO changes correspond to a line shifting from CCD4 to CCD1

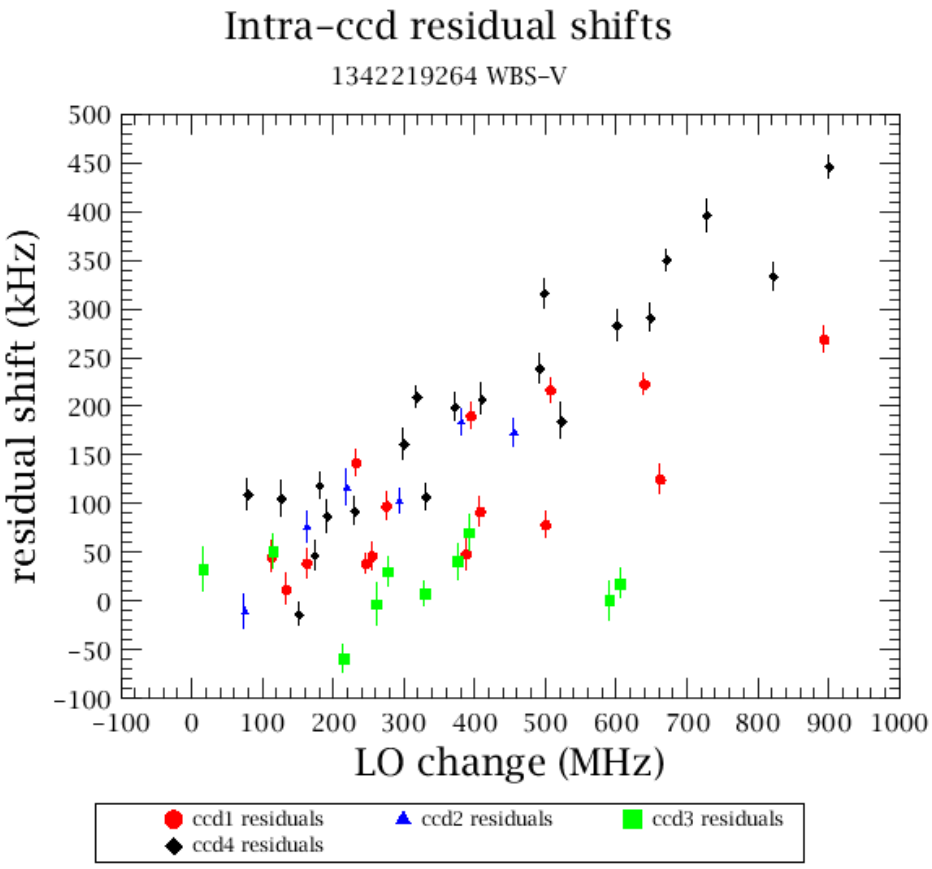


Figure 12: Test (C): Intra-ccd LO pairs only, HRSxWBS FCAL calibration (obsid 1342219264, WBS-V). CCD3 happened to be well calibrated by the nominal poly coefficients

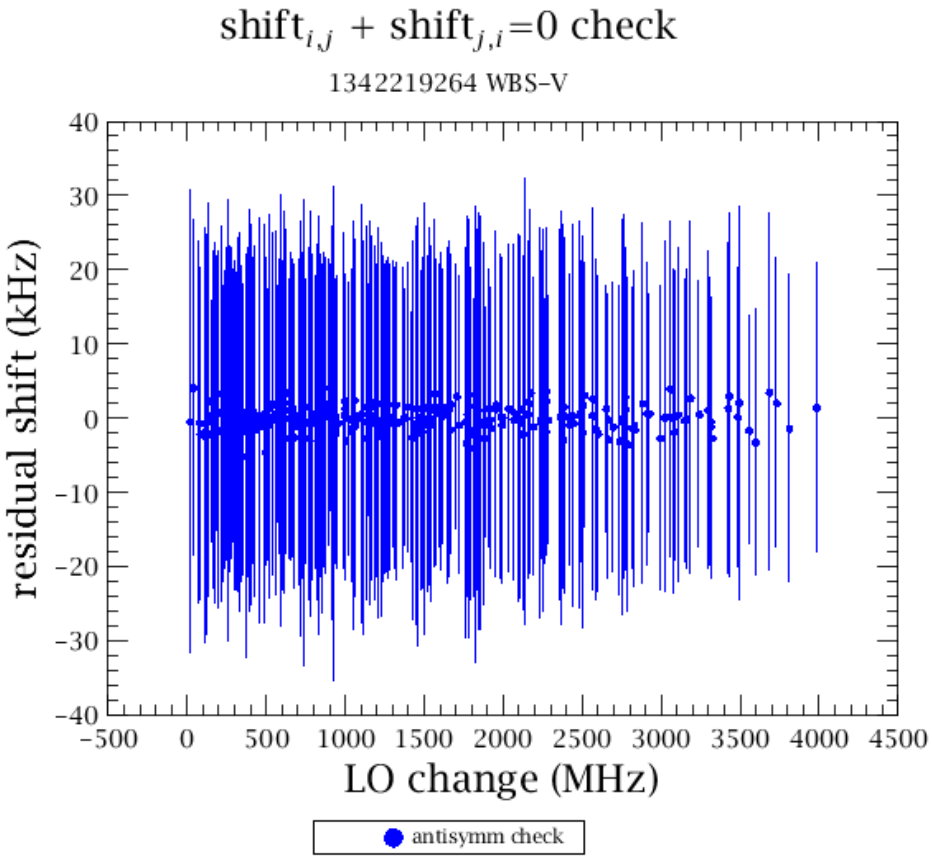


Figure 13: Test (C): For the FCAL obsid `1342219184`, a check on the consistency of the fits and error bars on shifted spectral lines: the shift of line $i$ to $j$ plus the shift of $j$ to $i$ should be zero. Similar to the plot for COMB calibration obsid `1342219185` 10, the accuracy on fitting line shifts seems to be $\lesssim$ 6 kHz

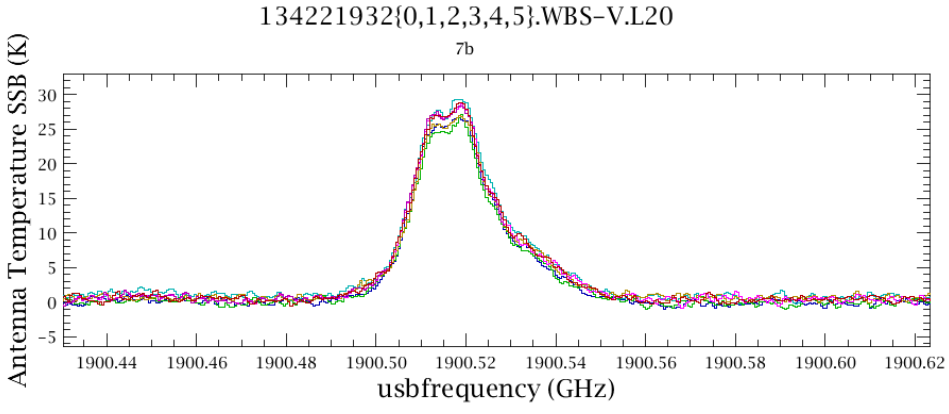


Figure 14: Test (D): All WBS-V Level2 spectra from Test (d) observations overplotted to show consistency of frequency calibration.