Investigation and correction of Herschel/HIFI spectral baseline artefacts

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Abstract

Using Herschel/HIFI data, we have performed an analysis of how artefacts affect the HIFI (Heterodyne Instrument for the Far-Infrared) spectra and how we can characterise them. For the purpose, every scientific observation done by HIFI is processed, in order to identify instrumental standing waves and extract from them some parameters that can be used to improve the HIFI calibration in the future.

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1 Introduction

1.1 The Data

The analysis includes data from all scientific observations done by HIFI, in which we consider:

Maps

Observations done in a fixed frequency, scanning a specific region of the sky. For the study we divide maps in two groups: planets (50 samples) and no planets (40 samples), each one containing a collection of hundreds of spectra.

Point

Same as maps, fixed frequency, but only in one position on the sky. It is the largest sample with over 9000 spectra, providing very robust statistics.

Scans

Each observation contains spectra of a single position measured in a certain range of frequencies.

1.2 Methods

Our first study involves the relationship between amplitudes of standing waves and thermal continuum present in spectra, being reasonable to expect linear depencence between them (the greater the continuum, the higher the amplitude). Some extra information must be obtained in order to do this.

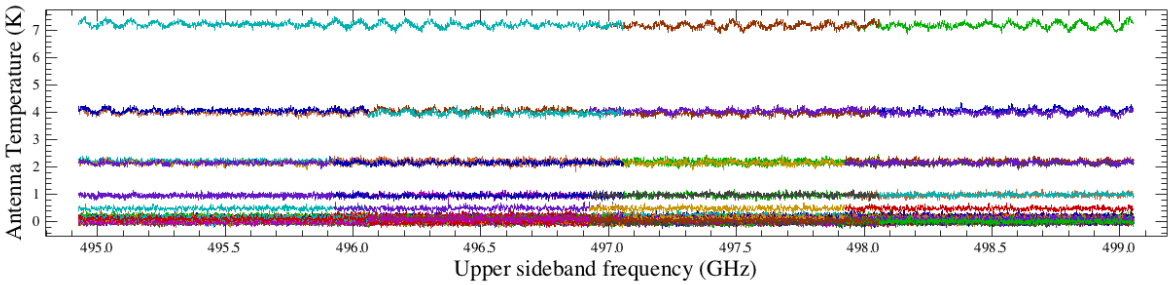


Figure 1: A tipical collection of spectra from HIFI, obtained on a map towards a planet (obsid 1342194179). It is clear that the amplitude of the standing waves increases with continuum (Antenna Temperature, in K).

Inside a spectrum, we have four items that affect our data, and must be characterized:

- Baseline: Particular shape of each signal that has to be corrected for analysis. For this purpose we have tested two methods. In the first one, each signal is smoothed with a function provided by HIPE. The function smoothes the data and substract the smoothed data to the original signal, getting a baseline-corrected spectrum:

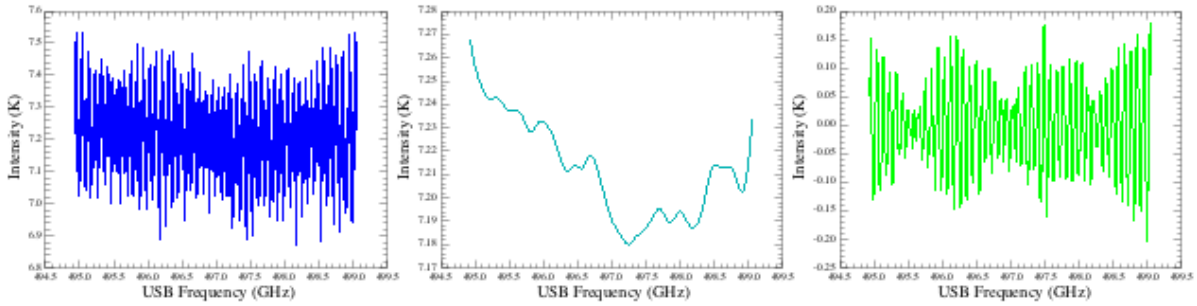


Figure 2: Example of smoothing (obsid 1342194179). Left: Raw signal, Center: Smoothed baseline, Right: Signal after baseline substraction.

In the second one, the signal is filtered with the baseline. As an example:

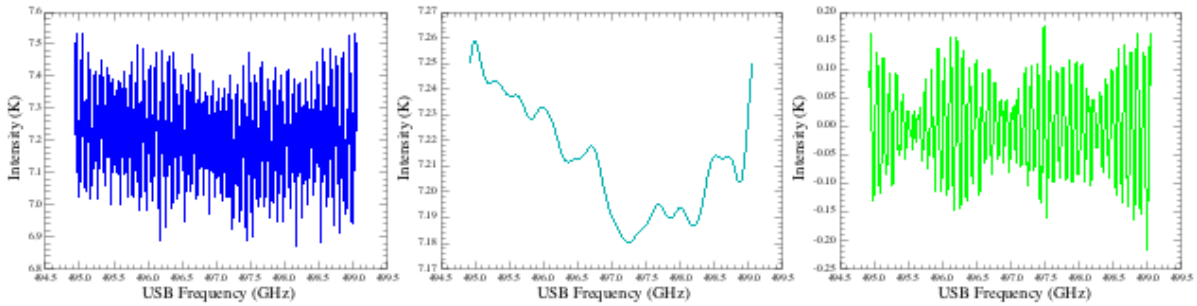


Figure 3: Example of filtering (obsid 1342194179). Left: Raw signal, Center: Filter, Right: Signal after filtering.

It is easy to notice that the results are practically the same for a given obsid, so at the end we have used filtering because it is a faster method in terms of computing.

- Continuum: Level of thermal radiation present in the signal, with a source instrumental or not. It is characterized as the mean of the signal.
- Noise: Includes photon noise from the detector which source is different from the object observed. For our calculations it is estimated as the standard deviation from the mean of the signal (continuum).
- Signal: Astrophysical information about the source observed. This one is provided by Nature and considered the only one which does not contain artifacts.

Amplitude

To estimate the amplitude three methods have been tested:

- "Minmax": Gets the amplitude as the difference between the maximum and the minimum intensity.
- "Standard deviation": Gets the amplitude as the standard deviation of the spectrum intensities.

- "FHF" (Fit HIFI Fringe): Based on Fourier series, tries to find a certain number (set as an input) of periodic structures (called fringes) present in data.

Obviously, the least accurate is "Minmax", the simple presence of a big outlier gives us a wrong amplitude. In case of "Standard deviation", we get the opposite, very robust against outliers, but the amplitudes obtained are smaller than the observed ones, and are mixed with noise. The best method then is "FHF", fitting amplitudes in Fourier series. This method, in fact, gives us additional information about the presence of standing waves in each spectrum.

New parameter space

Thanks to the Fourier analysis, we can get amplitudes much more accurately than before, but is not the only advantage: the FHF tool allows us to get periods. Each time we call FHF tool, we ask the program to find a number of fringes (input) each with a period and amplitude, being the perfect tool for finding standing waves in any signal. Now we can start the analysis with:

- Continuum: as the mean of the signal.
- Amplitude: one for each fringe, obtained with FHF.
- Period: one for each fringe, obtained with FHF.
- Frequency: provided with the signal.
- Noise: obtained as the standard deviation from the mean.
- S/N: the ratio between amplitude and noise.

The data is tabulated and stored in FITS files for each observation mode, band and polarization.

2 Standing waves

With the data stored, the next step is the localization of standing waves. For the purpose are used two methods, one based on histograms (presence) and the other on signal to noise values (weight).

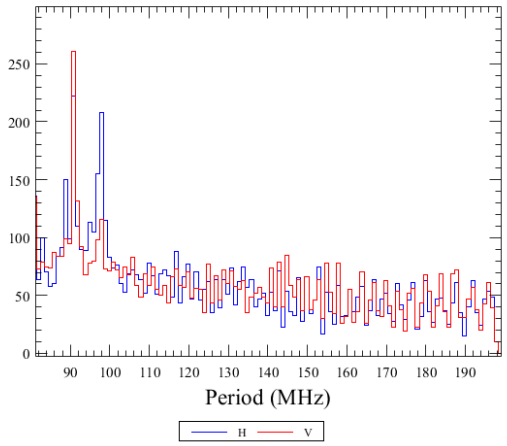
2.1 Presence

The tool developed takes all period values on each summary and returns a histogram, in both polarizations. Based on them we can assure the presence of a certain period in the signal. Bands are set in four groups due to similarities in histograms and results are displayed per band, distinguishing between modes.

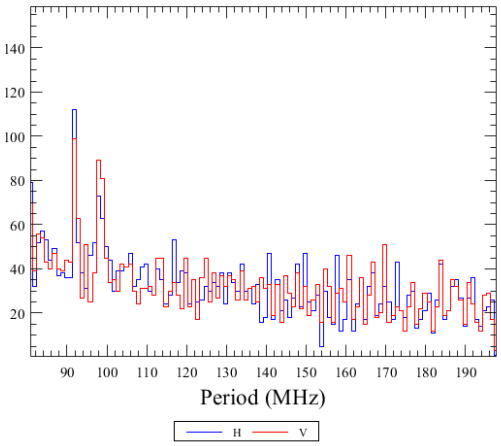
The bins used in the histograms are 0.5 MHz for bands 1 and 2, and 5 MHz fot bands 3 to 7. As a consequence, the true standing waves at 90 and 100 MHz are blended in these plots.

Bands 1 and 2

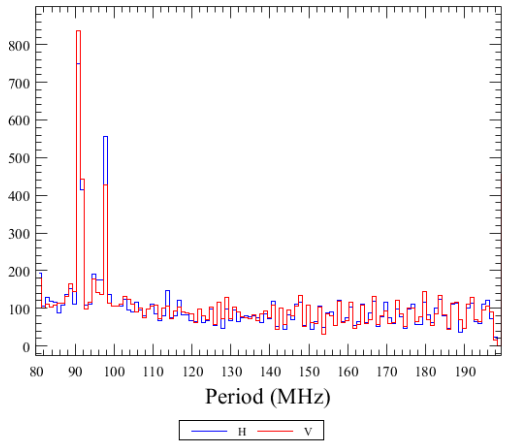
Map mode band 1



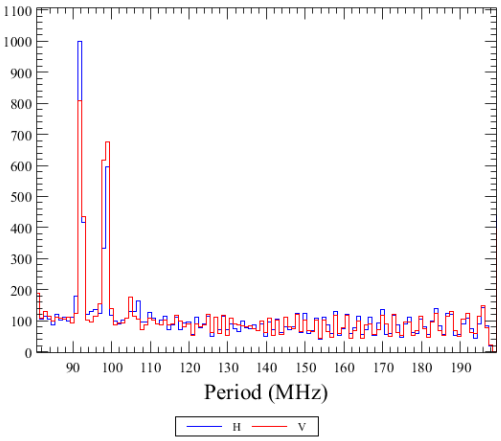
Map mode band 2



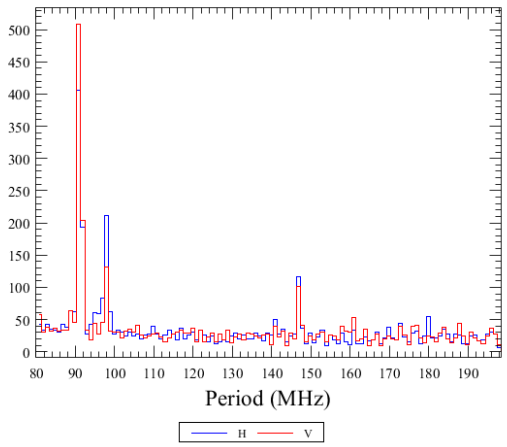
Scan mode band 1



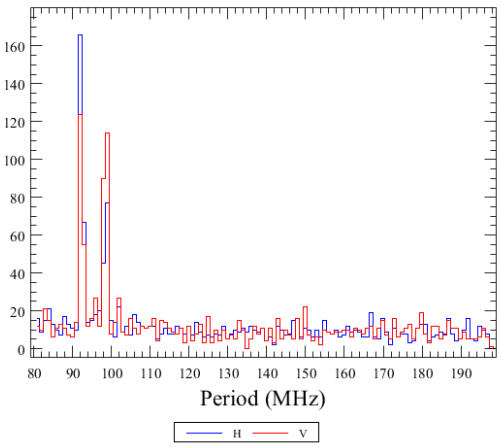
Scan mode band 2



Point mode band 1

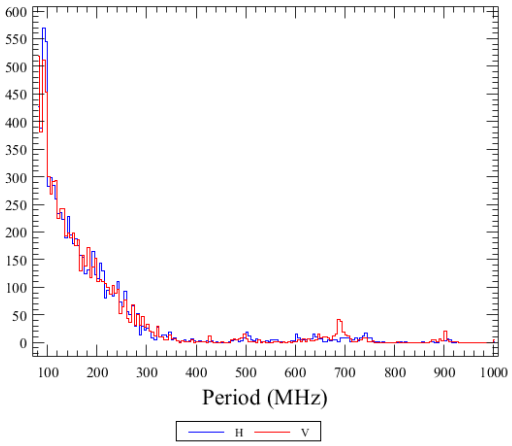


Point mode band 2

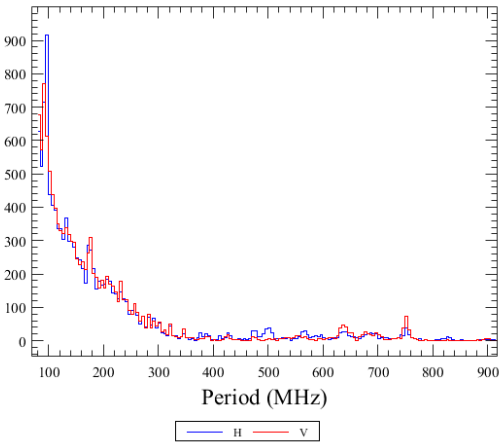


Bands 3 and 4

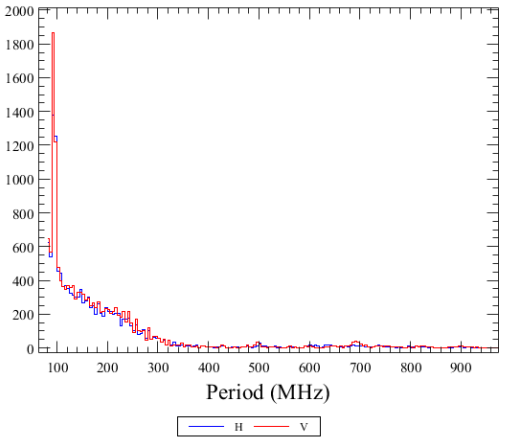
Map mode band 3



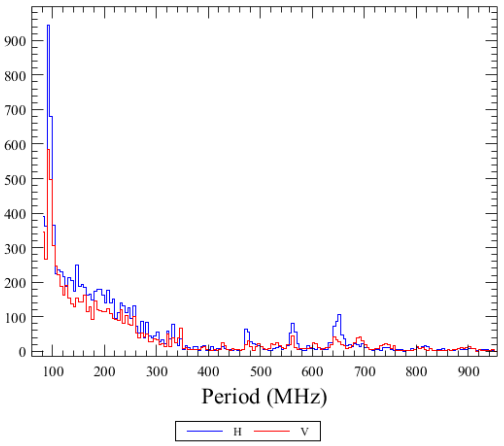
Map mode band 4



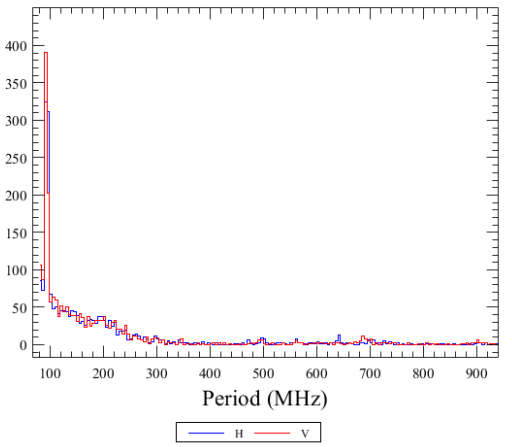
Scan mode band 3



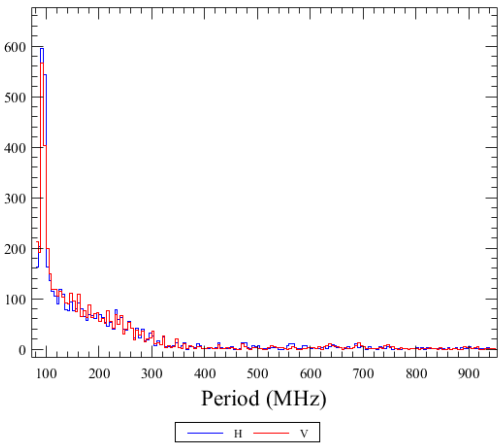
Scan mode band 4



Point mode band 3

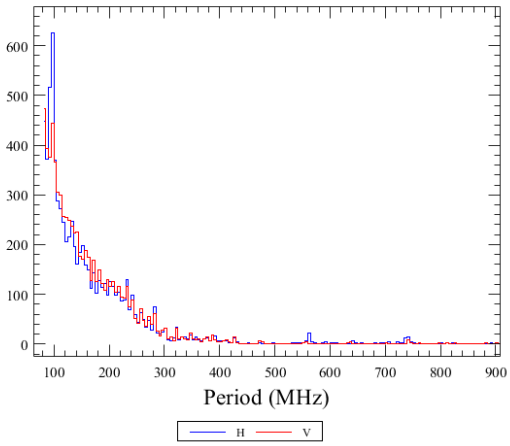


Point mode band 4

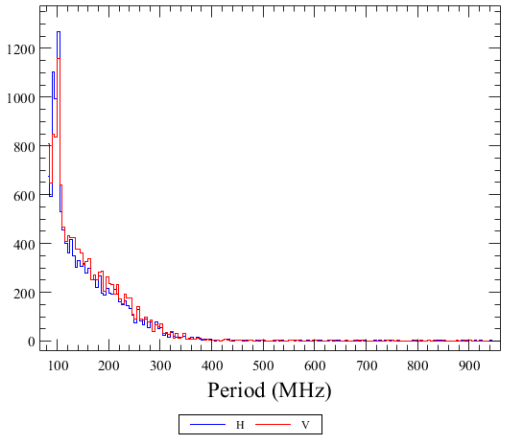


Band 5

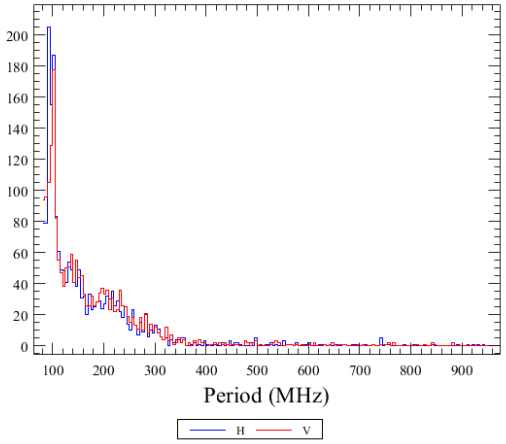
Map mode band 5



Scan mode band 5

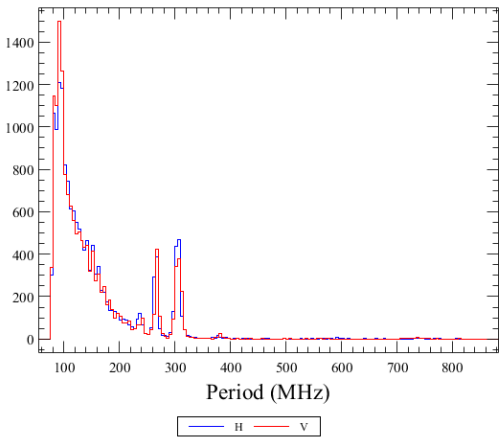


Point mode band 5

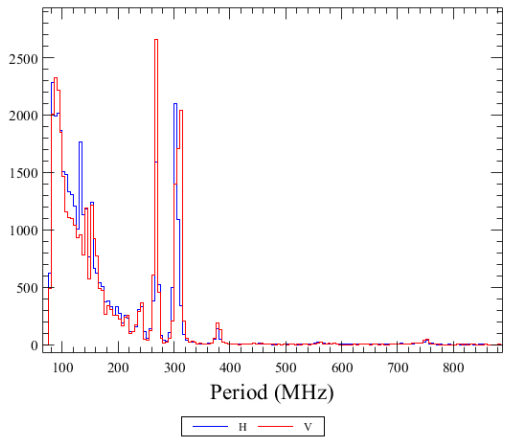


Bands 6 and 7

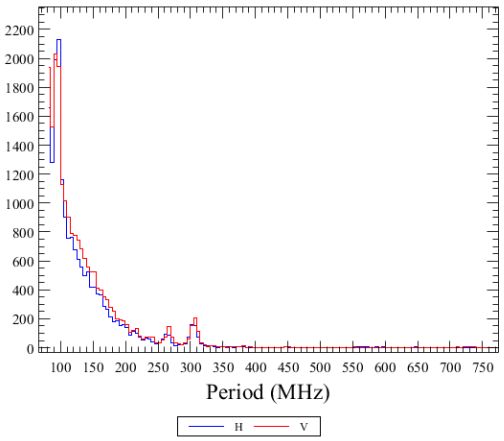
Map mode band 6



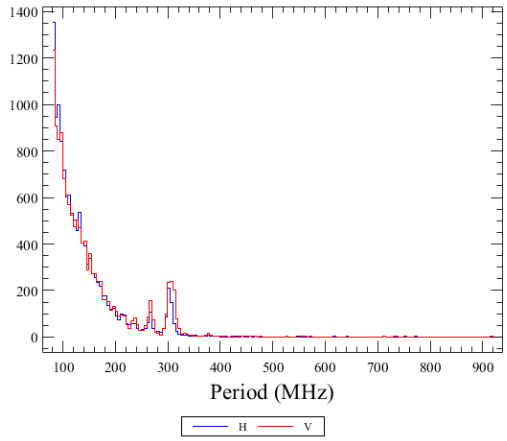
Map mode band 7



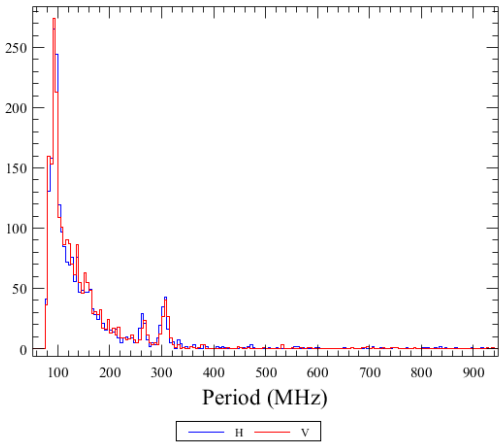
Scan mode band 6



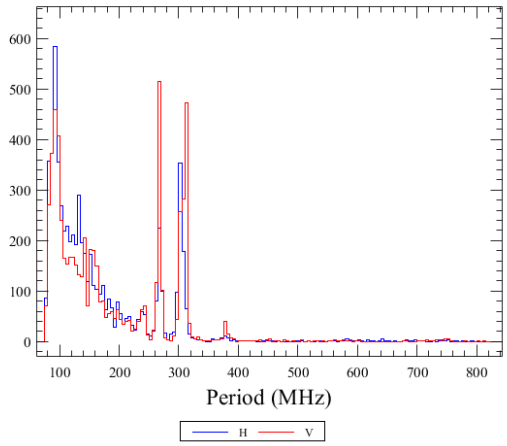
Scan mode band 7



Point mode band 6



Point mode band 7



Period Origin	90 MHz Hot load	100 MHz Cold load	144 MHz ?	270 MHz ESW	300 MHz ESW	650 MHz Diplexer
Band 1	All	All	Point	-	-	-
Band 2	All	All	-	-	-	-
Band 3	All	All	-	-	-	Map
Band 4	All	All	-	-	-	M, Sc
Band 5	All	All	-	-	-	-
Band 6	All	All	-	All	All	-
Band 7	All	All	-	All	All	-

Table 1: Standing waves present in data according to histograms. ESW means electrical standing wave

Standing waves

The information provided by histograms shows us the presence of the typical standing waves:

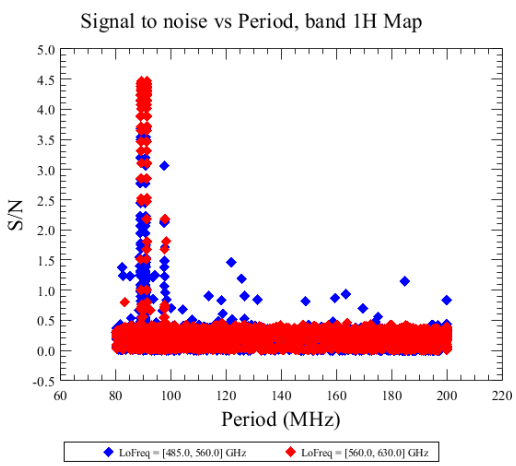
The table shows for which mode the presence of each possible standing wave found in histogramsis is statistically significant. Periods are taken as guide values, further analysis of each standing wave are neccesary to improve the accuracy.

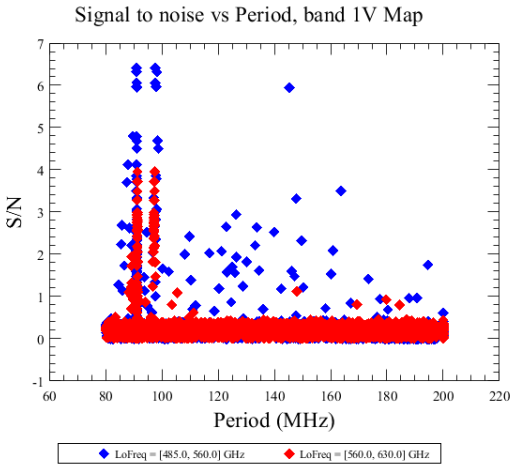
It is interesting to note that in every band and mode the 90 and 100 MHz standing waves are present, while other ones are significant only in certain bands (270, 300 MHz in bands 6 and 7). In every case, the 650 MHz standing wave is really low, being only significant in bands 3 and 4. This standing wave is known, but is really affected by noise. As an outlier, the 144 MHz standing wave appears only in band 1 and point mode, which is the largest sample.

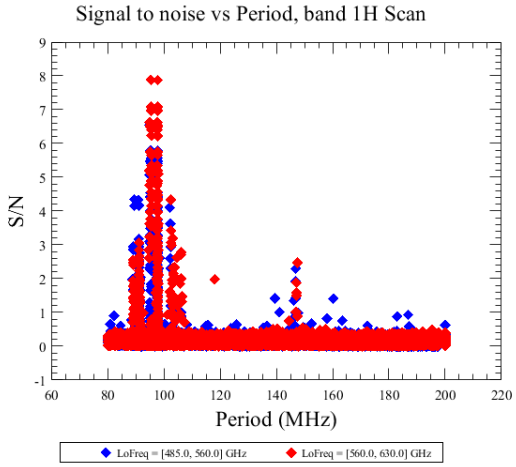
2.2 Signal to noise analysis

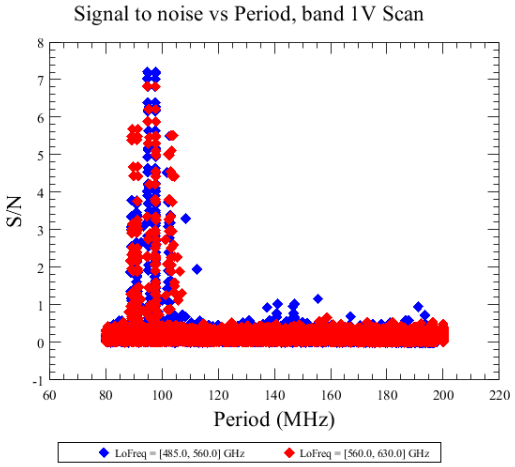
While in histograms we extract information about the statistical importance (or presence) of periods of standing waves, signal to noise plots give us information about amplitudes. It is an interesting tool for confirmation of presence of standing waves as well as new information that could be hidden inside histograms. In this case plots are shown by polarization, mode and band, splitting the frequency range in two sections, blue and red.

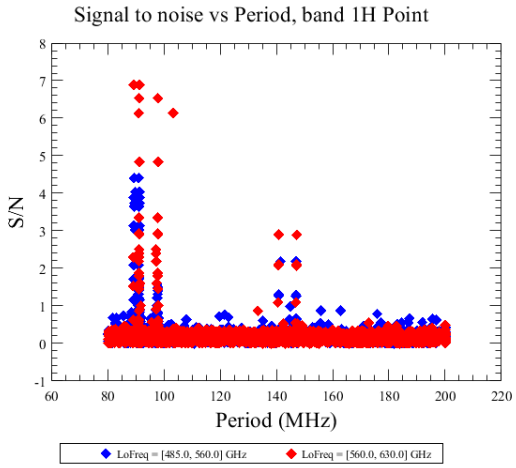
Band 1

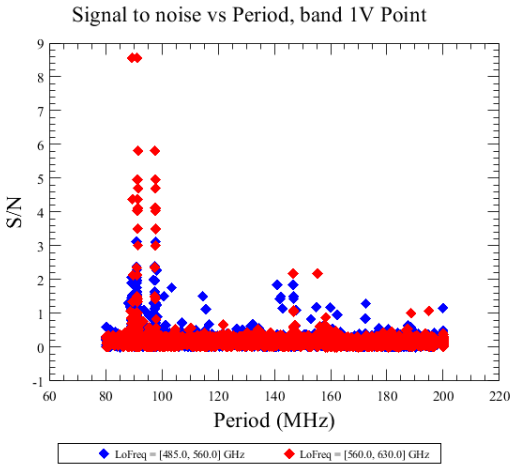

Signal to noise vs Period, band 1H Map
S/N
Period (MHz)
LoFreq = [485.0, 560.0] GHz
LoFreq = [560.0, 630.0] GHz


Signal to noise vs Period, band 1V Map
S/N
Period (MHz)
LoFreq = [485.0, 560.0] GHz
LoFreq = [560.0, 630.0] GHz

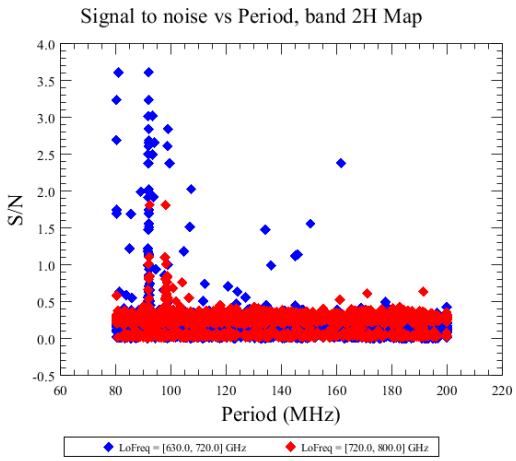

Signal to noise vs Period, band 1H Scan
S/N
Period (MHz)
LoFreq = [485.0, 560.0] GHz
LoFreq = [560.0, 630.0] GHz

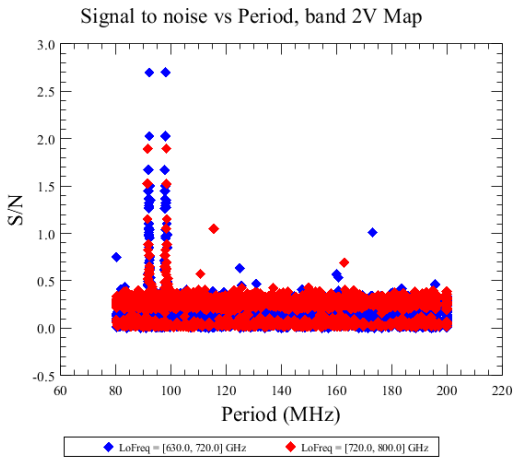

Signal to noise vs Period, band 1V Scan
S/N
Period (MHz)
LoFreq = [485.0, 560.0] GHz
LoFreq = [560.0, 630.0] GHz

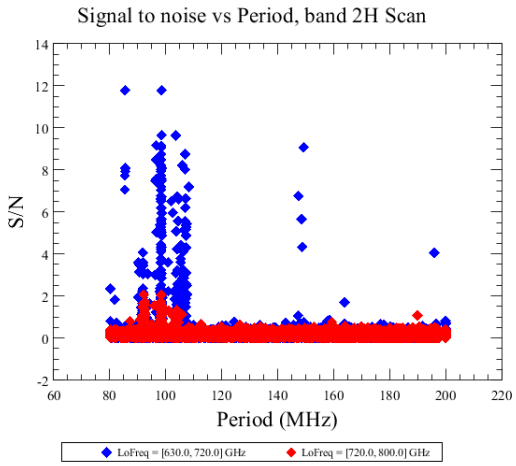

Signal to noise vs Period, band 1H Point
S/N
Period (MHz)
LoFreq = [485.0, 560.0] GHz
LoFreq = [560.0, 630.0] GHz

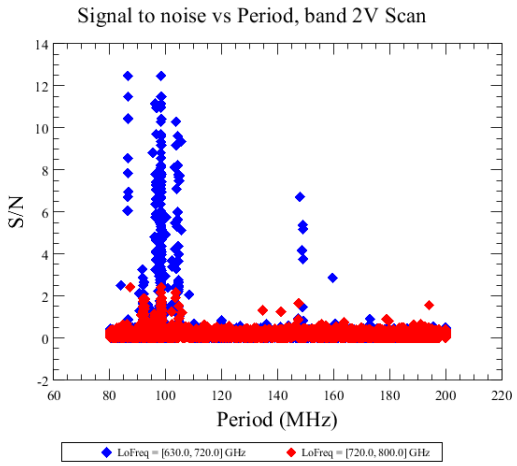

Signal to noise vs Period, band 1V Point
S/N
Period (MHz)
LoFreq = [485.0, 560.0] GHz
LoFreq = [560.0, 630.0] GHz

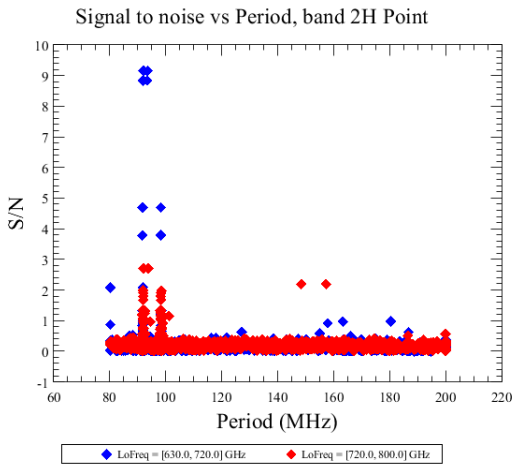
Band 2

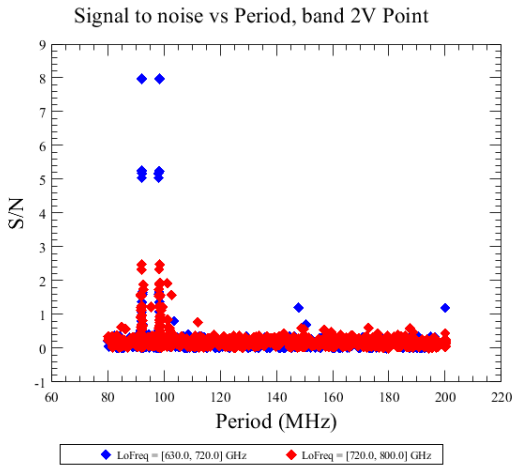

Signal to noise vs Period, band 2H Map
S/N
Period (MHz)
LoFreq = [630.0, 720.0] GHz
LoFreq = [720.0, 800.0] GHz


Signal to noise vs Period, band 2V Map
S/N
Period (MHz)
LoFreq = [630.0, 720.0] GHz
LoFreq = [720.0, 800.0] GHz


Signal to noise vs Period, band 2H Scan
S/N
Period (MHz)
LoFreq = [630.0, 720.0] GHz
LoFreq = [720.0, 800.0] GHz

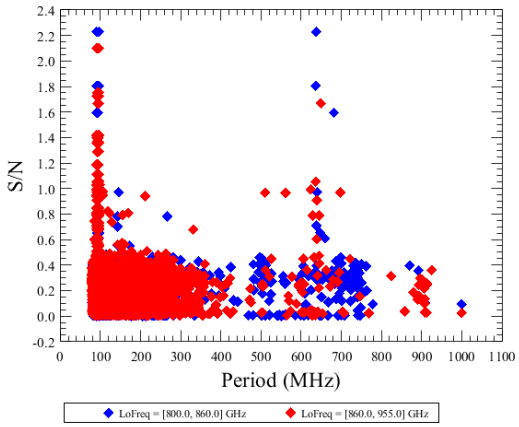

Signal to noise vs Period, band 2V Scan
S/N
Period (MHz)
LoFreq = [630.0, 720.0] GHz
LoFreq = [720.0, 800.0] GHz


Signal to noise vs Period, band 2H Point
S/N
Period (MHz)
LoFreq = [630.0, 720.0] GHz
LoFreq = [720.0, 800.0] GHz

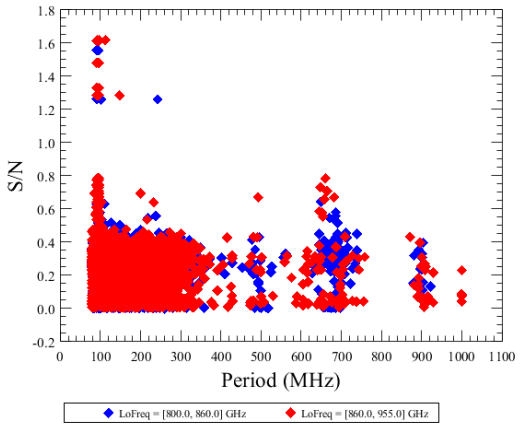

Signal to noise vs Period, band 2V Point
S/N
Period (MHz)
LoFreq = [630.0, 720.0] GHz
LoFreq = [720.0, 800.0] GHz

Band 3

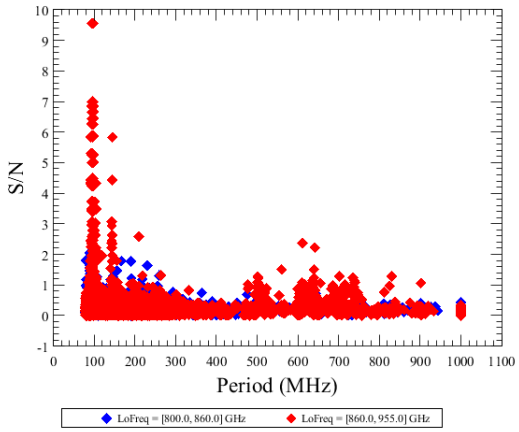
Signal to noise vs Period, band 3H Map



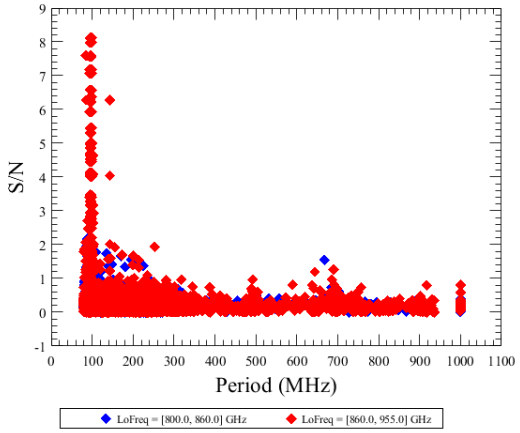
Signal to noise vs Period, band 3V Map



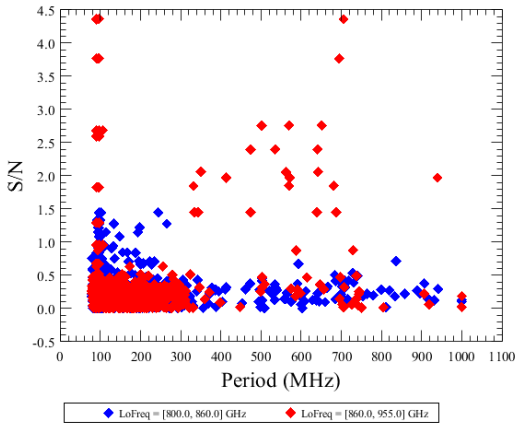
Signal to noise vs Period, band 3H Scan



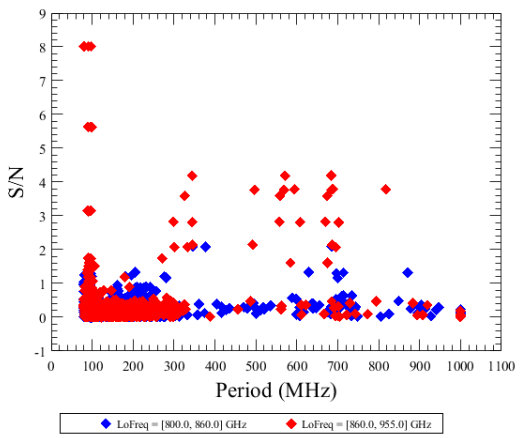
Signal to noise vs Period, band 3V Scan



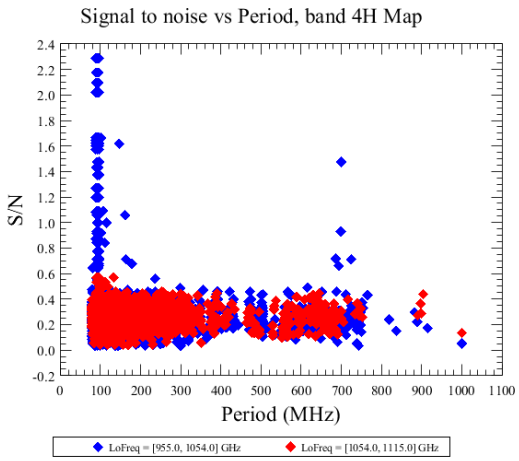
Signal to noise vs Period, band 3H Point

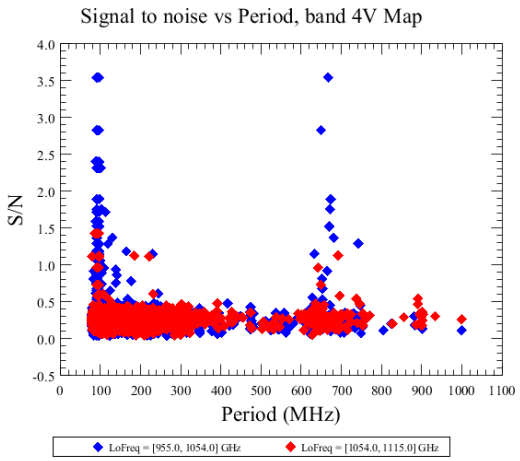


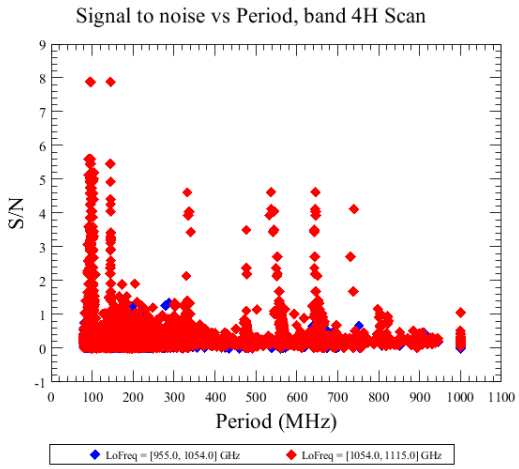
Signal to noise vs Period, band 3V Point

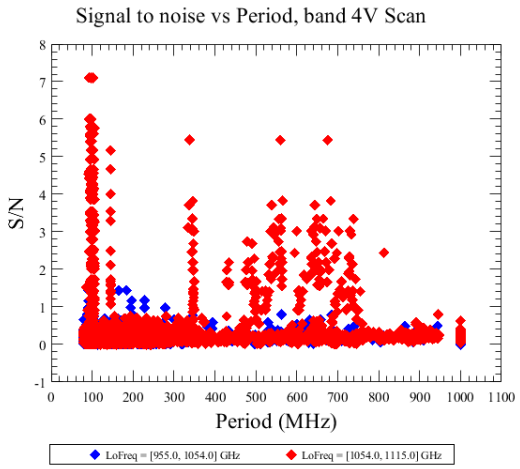


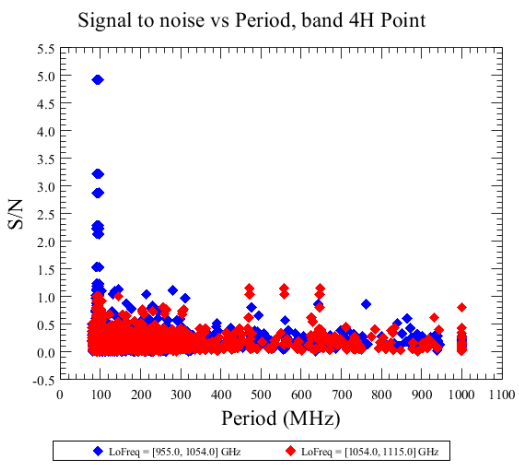
Band 4

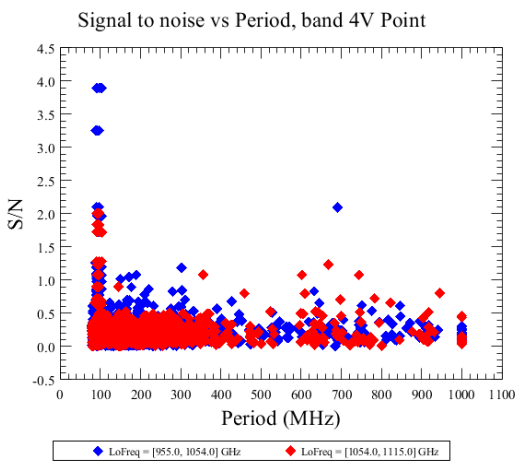

Signal to noise vs Period, band 4H Map
S/N
Period (MHz)
LoFreq = [955.0, 1054.0] GHz
LoFreq = [1054.0, 1115.0] GHz


Signal to noise vs Period, band 4V Map
S/N
Period (MHz)
LoFreq = [955.0, 1054.0] GHz
LoFreq = [1054.0, 1115.0] GHz

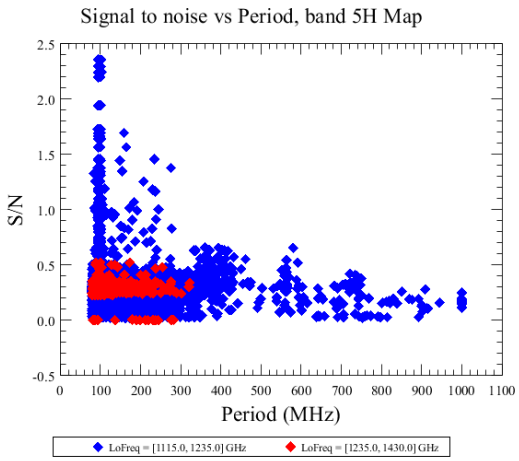

Signal to noise vs Period, band 4H Scan
S/N
Period (MHz)
LoFreq = [955.0, 1054.0] GHz
LoFreq = [1054.0, 1115.0] GHz

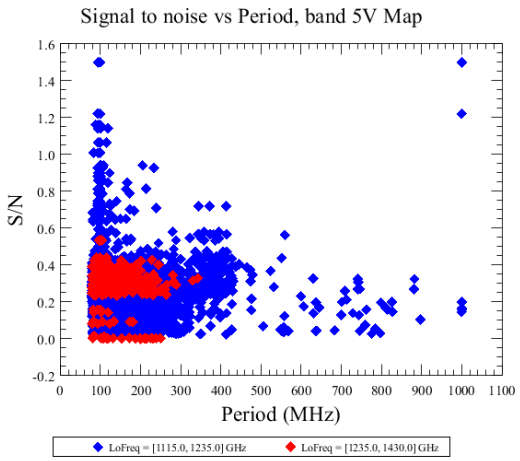

Signal to noise vs Period, band 4V Scan
S/N
Period (MHz)
LoFreq = [955.0, 1054.0] GHz
LoFreq = [1054.0, 1115.0] GHz

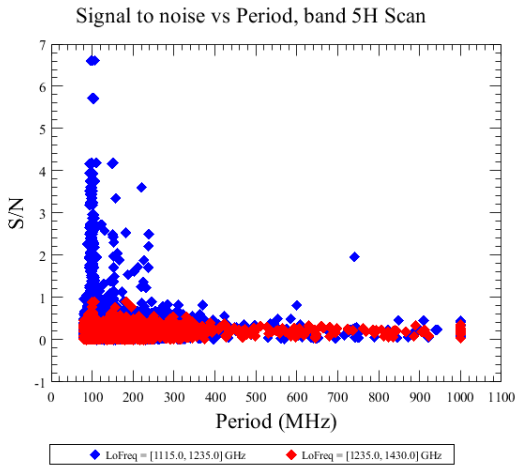

Signal to noise vs Period, band 4H Point
S/N
Period (MHz)
LoFreq = [955.0, 1054.0] GHz
LoFreq = [1054.0, 1115.0] GHz

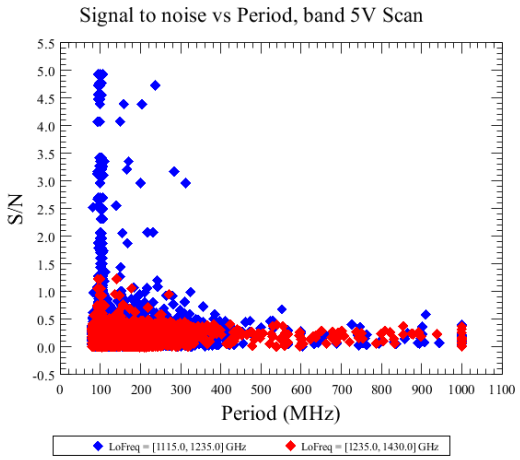

Signal to noise vs Period, band 4V Point
S/N
Period (MHz)
LoFreq = [955.0, 1054.0] GHz
LoFreq = [1054.0, 1115.0] GHz

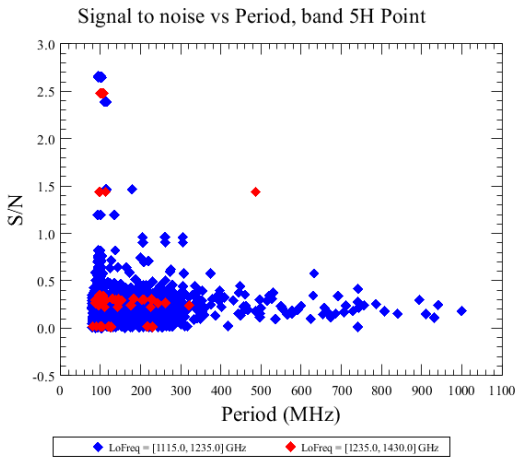
Band 5

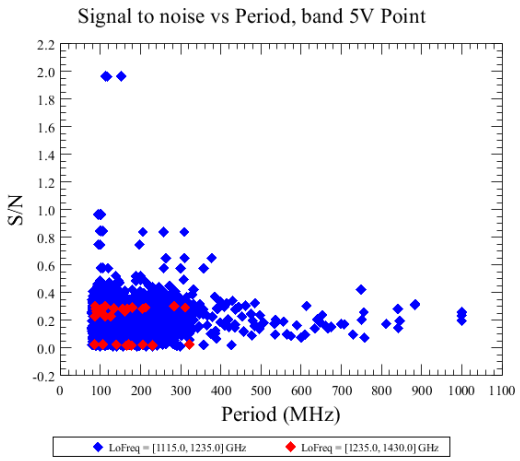

Signal to noise vs Period, band 5H Map
S/N
Period (MHz)
LoFreq = [1115.0, 1235.0] GHz
LoFreq = [1235.0, 1430.0] GHz


Signal to noise vs Period, band 5V Map
S/N
Period (MHz)
LoFreq = [1115.0, 1235.0] GHz
LoFreq = [1235.0, 1430.0] GHz


Signal to noise vs Period, band 5H Scan
S/N
Period (MHz)
LoFreq = [1115.0, 1235.0] GHz
LoFreq = [1235.0, 1430.0] GHz

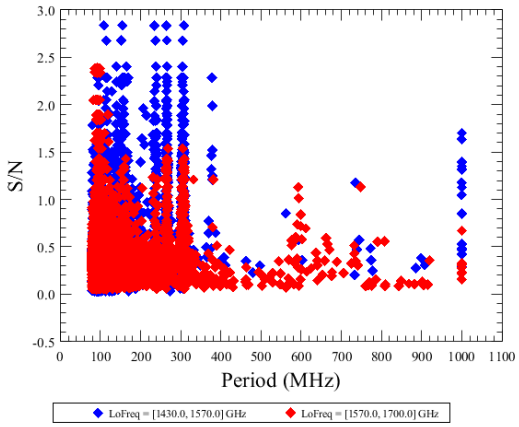

Signal to noise vs Period, band 5V Scan
S/N
Period (MHz)
LoFreq = [1115.0, 1235.0] GHz
LoFreq = [1235.0, 1430.0] GHz


Signal to noise vs Period, band 5H Point
S/N
Period (MHz)
LoFreq = [1115.0, 1235.0] GHz
LoFreq = [1235.0, 1430.0] GHz

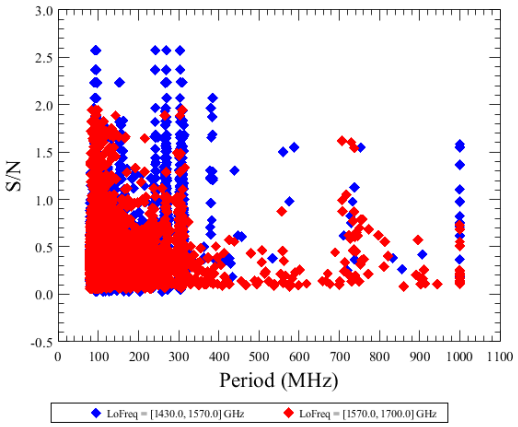

Signal to noise vs Period, band 5V Point
S/N
Period (MHz)
LoFreq = [1115.0, 1235.0] GHz
LoFreq = [1235.0, 1430.0] GHz

Band 6

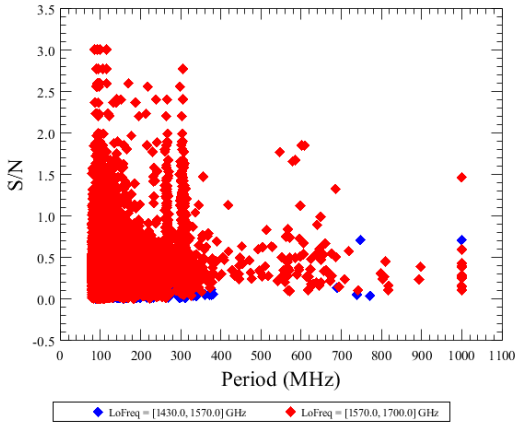
Signal to noise vs Period, band 6H Map



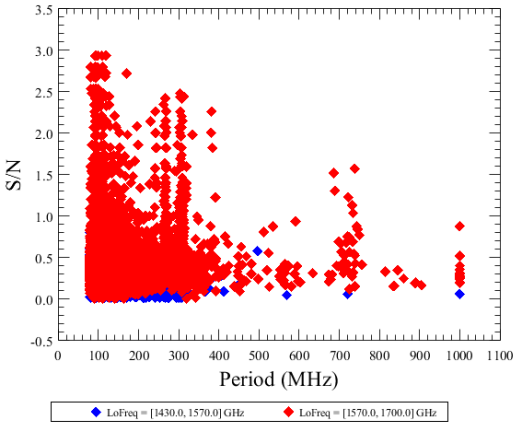
Signal to noise vs Period, band 6V Map



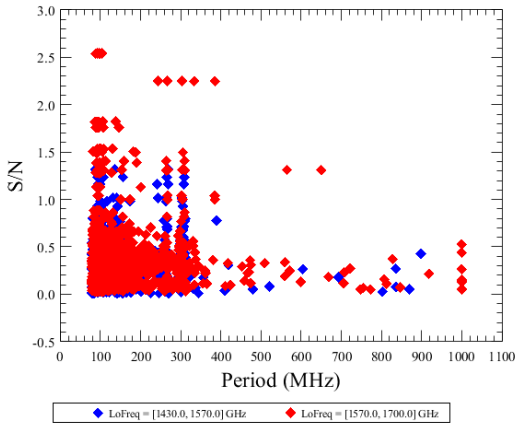
Signal to noise vs Period, band 6H Scan



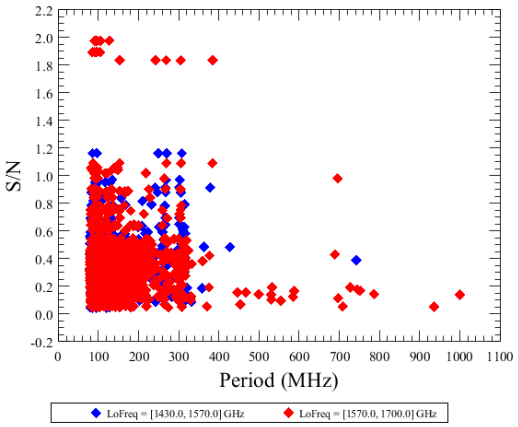
Signal to noise vs Period, band 6V Scan



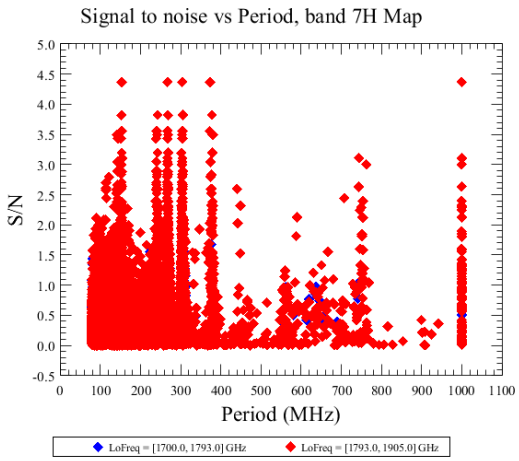
Signal to noise vs Period, band 6H Point

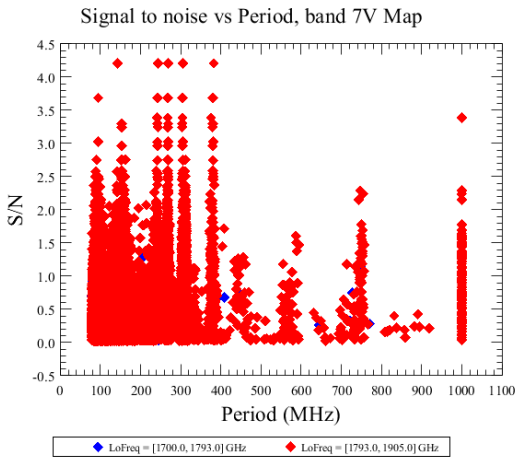


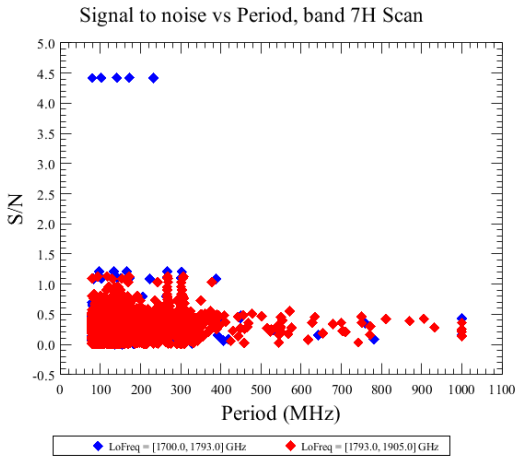
Signal to noise vs Period, band 6V Point

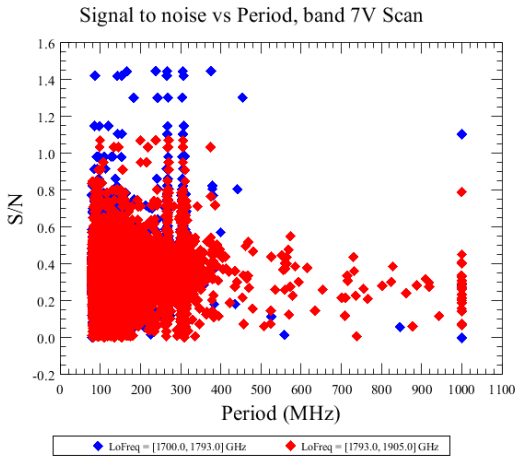


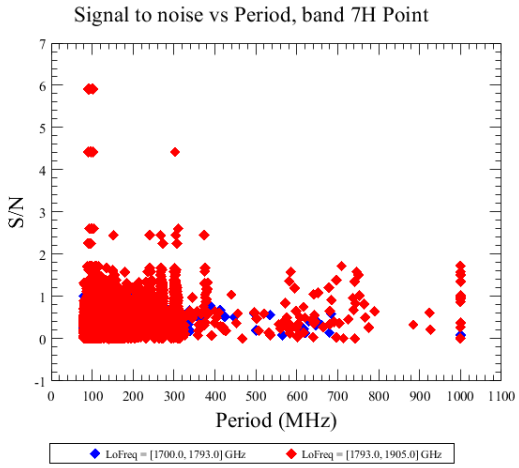
Band 7

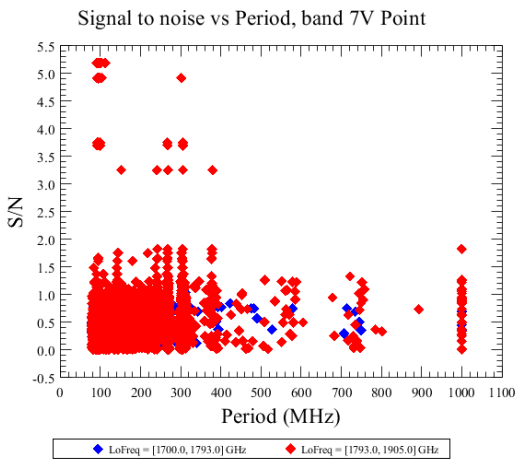

Signal to noise vs Period, band 7H Map
S/N
Period (MHz)
LoFreq = [1700.0, 1793.0] GHz
LoFreq = [1793.0, 1905.0] GHz


Signal to noise vs Period, band 7V Map
S/N
Period (MHz)
LoFreq = [1700.0, 1793.0] GHz
LoFreq = [1793.0, 1905.0] GHz


Signal to noise vs Period, band 7H Scan
S/N
Period (MHz)
LoFreq = [1700.0, 1793.0] GHz
LoFreq = [1793.0, 1905.0] GHz


Signal to noise vs Period, band 7V Scan
S/N
Period (MHz)
LoFreq = [1700.0, 1793.0] GHz
LoFreq = [1793.0, 1905.0] GHz


Signal to noise vs Period, band 7H Point
S/N
Period (MHz)
LoFreq = [1700.0, 1793.0] GHz
LoFreq = [1793.0, 1905.0] GHz


Signal to noise vs Period, band 7V Point
S/N
Period (MHz)
LoFreq = [1700.0, 1793.0] GHz
LoFreq = [1793.0, 1905.0] GHz

As expected, standing waves appear again in these plots. It is important to remark that although there are more peaks in some plots than in each corresponding histogram, this does not mean that there are more standing waves, because their presence is not significant (it's only a period in which S/N is high, but could be unique). These plots also confirm that the 144 MHz Point standing wave in band 1 is significant.

3 Statistical study of slopes

With standing waves identified, the next step is a deeper statistical analysis browsing through their parameters. In the next sections, an analysis of the behaviour of amplitudes with continua is done in every mode, band, polarization and frequency, extracting data that could be useful for calibrations. Finally, results are summarized and scatter plots are created.

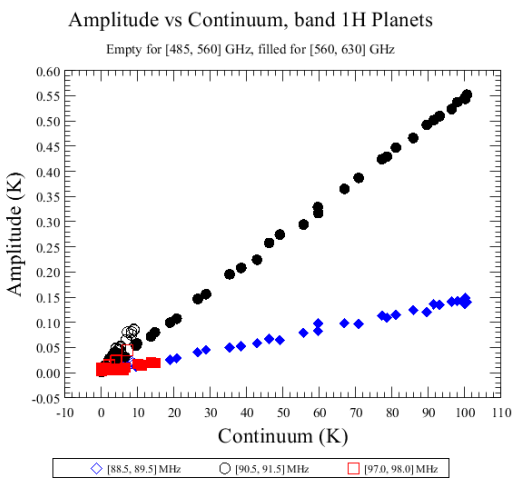
3.1 Amplitude vs. Continuum

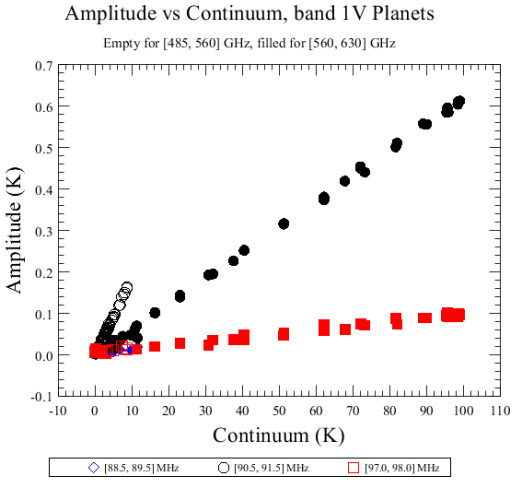
As continuum increases, one can expect a similar behaviour for amplitudes. The question is how this relationship aproaches to a linear one, and the differences between modes.

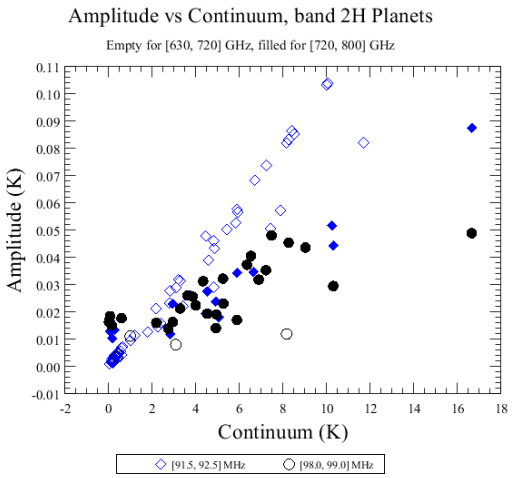
For these plots we have separated maps between planets and not. After seeing that planet obsids are responsible for standing waves in maps and because they have stronger continua, no-planet map obsids have been discarded for the analysis.

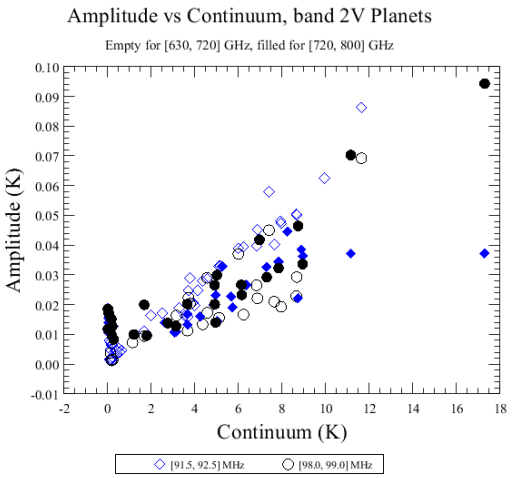
Data has been summarized, identifying standing waves in specific ranges for each of them (depending on the size of the peaks in histograms). The next plots show the results, by mode and polarization, with different and colours for each standing wave and filled shapes or not depending on the frequency range.

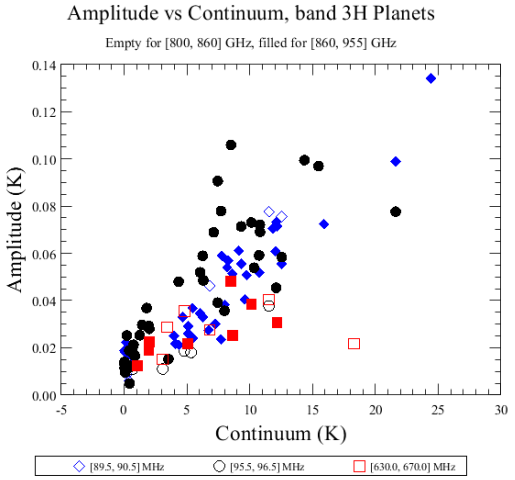
Planets 1,2,3

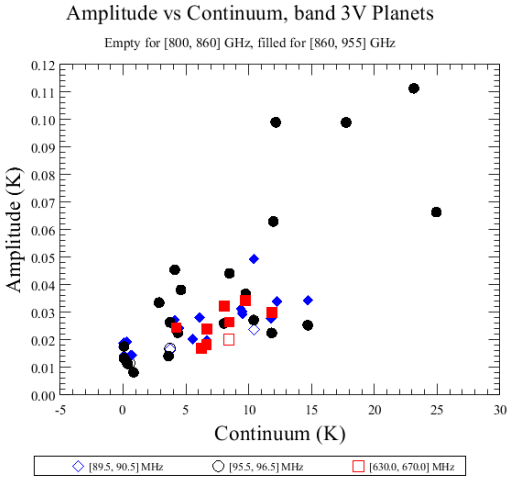

Amplitude vs Continuum, band 1H Planets
Empty for [485, 560] GHz, filled for [560, 630] GHz
Amplitude (K)
Continuum (K)
[88.5, 89.5] MHz
[90.5, 91.5] MHz
[97.0, 98.0] MHz


Amplitude vs Continuum, band 1V Planets
Empty for [485, 560] GHz, filled for [560, 630] GHz
Amplitude (K)
Continuum (K)
[88.5, 89.5] MHz
[90.5, 91.5] MHz
[97.0, 98.0] MHz

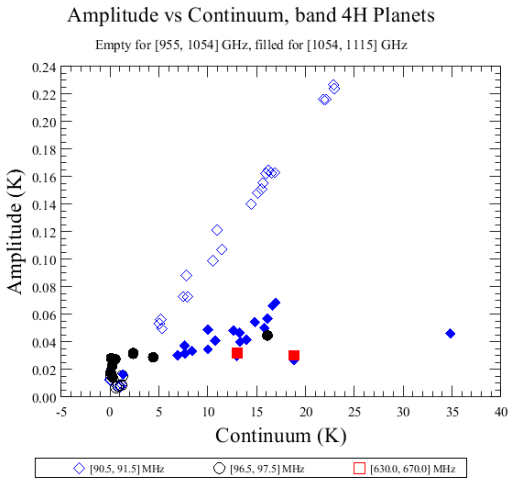

Amplitude vs Continuum, band 2H Planets
Empty for [630, 720] GHz, filled for [720, 800] GHz
Amplitude (K)
Continuum (K)
[91.5, 92.5] MHz
[98.0, 99.0] MHz

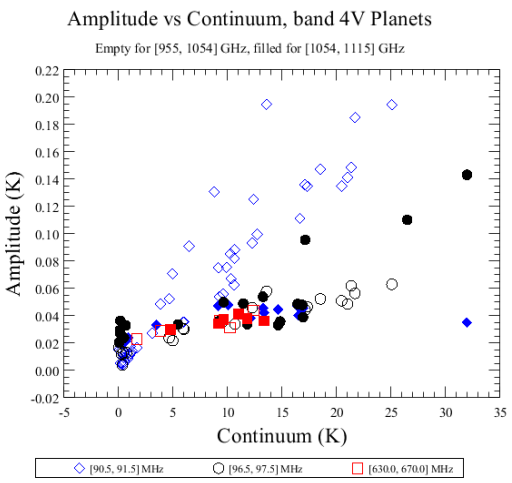

Amplitude vs Continuum, band 2V Planets
Empty for [630, 720] GHz, filled for [720, 800] GHz
Amplitude (K)
Continuum (K)
[91.5, 92.5] MHz
[98.0, 99.0] MHz

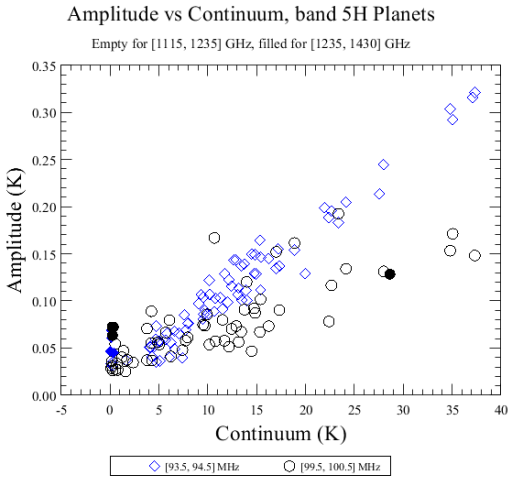

Amplitude vs Continuum, band 3H Planets
Empty for [800, 860] GHz, filled for [860, 955] GHz
Amplitude (K)
Continuum (K)
[89.5, 90.5] MHz
[95.5, 96.5] MHz
[630.0, 670.0] MHz

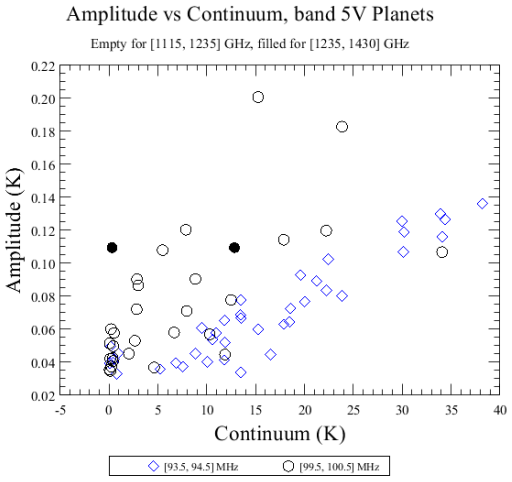

Amplitude vs Continuum, band 3V Planets
Empty for [800, 860] GHz, filled for [860, 955] GHz
Amplitude (K)
Continuum (K)
[89.5, 90.5] MHz
[95.5, 96.5] MHz
[630.0, 670.0] MHz

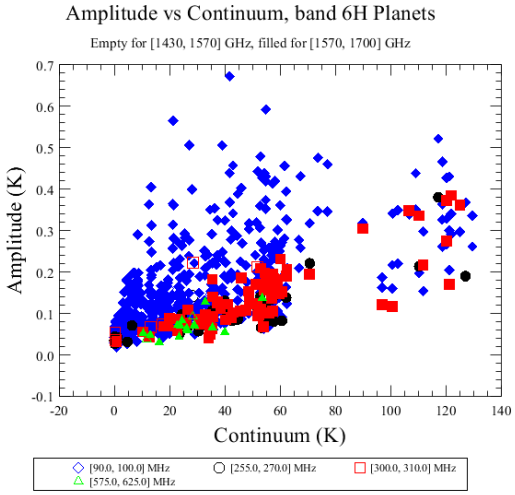
Planets 4,5,6

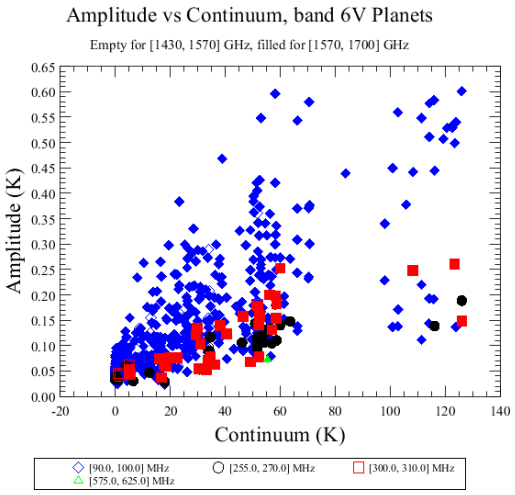

Amplitude vs Continuum, band 4H Planets
Empty for [955, 1054] GHz, filled for [1054, 1115] GHz
Amplitude (K)
Continuum (K)
[90.5, 91.5] MHz
[96.5, 97.5] MHz
[630.0, 670.0] MHz


Amplitude vs Continuum, band 4V Planets
Empty for [955, 1054] GHz, filled for [1054, 1115] GHz
Amplitude (K)
Continuum (K)
[90.5, 91.5] MHz
[96.5, 97.5] MHz
[630.0, 670.0] MHz

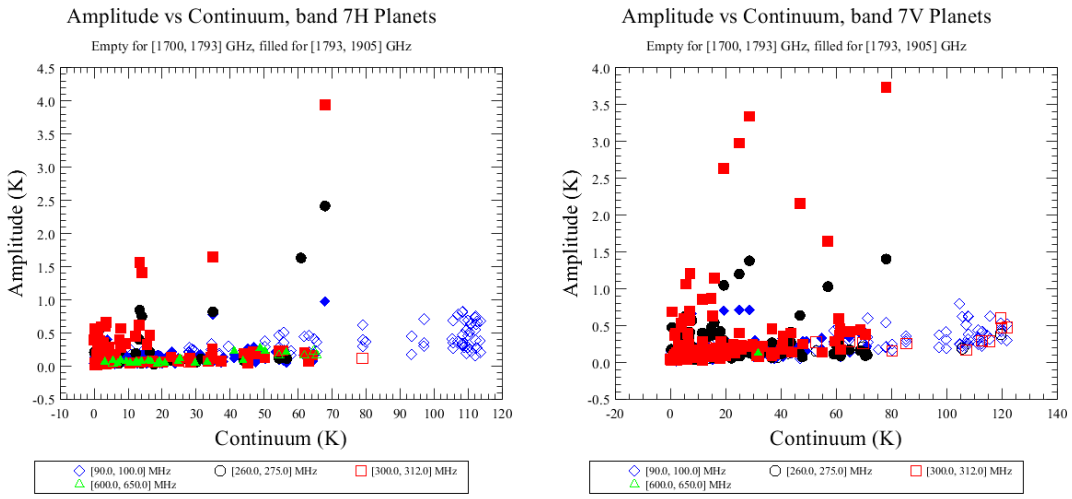

Amplitude vs Continuum, band 5H Planets
Empty for [1115, 1235] GHz, filled for [1235, 1430] GHz
Amplitude (K)
Continuum (K)
[93.5, 94.5] MHz
[99.5, 100.5] MHz


Amplitude vs Continuum, band 5V Planets
Empty for [1115, 1235] GHz, filled for [1235, 1430] GHz
Amplitude (K)
Continuum (K)
[93.5, 94.5] MHz
[99.5, 100.5] MHz


Amplitude vs Continuum, band 6H Planets
Empty for [1430, 1570] GHz, filled for [1570, 1700] GHz
Amplitude (K)
Continuum (K)
[90.0, 100.0] MHz
[255.0, 270.0] MHz
[300.0, 310.0] MHz
[575.0, 625.0] MHz

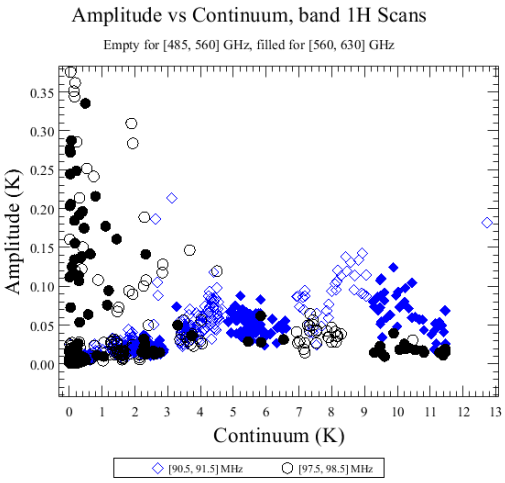

Amplitude vs Continuum, band 6V Planets
Empty for [1430, 1570] GHz, filled for [1570, 1700] GHz
Amplitude (K)
Continuum (K)
[90.0, 100.0] MHz
[255.0, 270.0] MHz
[300.0, 310.0] MHz
[575.0, 625.0] MHz

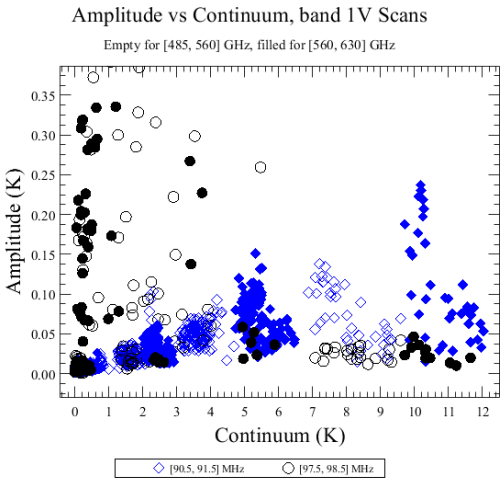
Planets 7

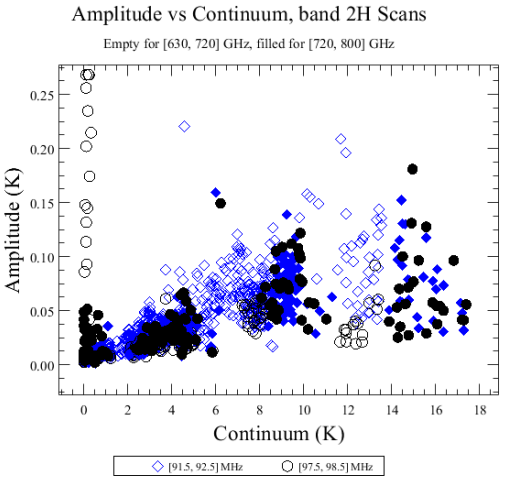


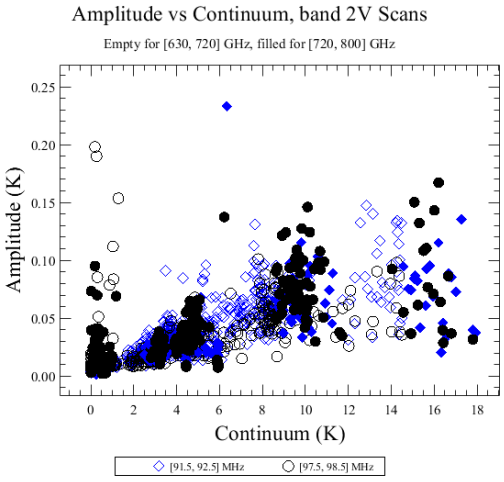
Plots show a strong linear behaviour in lower bands, specially in 1 and 2. In fact, it is remarkable that for each frequency and standing wave, there is one slope. As frequency increases linear shape hides behind noise and it is difficult to find if there is one slope or more for each frequency and standing wave (bands 6 and 7).

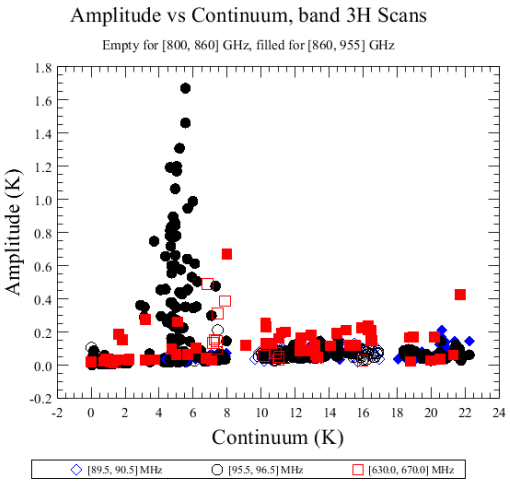
Scans 1,2,3

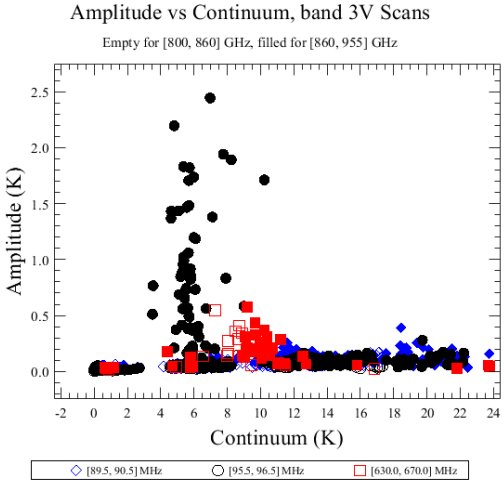

Amplitude vs Continuum, band 1H Scans
Empty for [485, 560] GHz, filled for [560, 630] GHz
Amplitude (K)
Continuum (K)
[90.5, 91.5] MHz
[97.5, 98.5] MHz


Amplitude vs Continuum, band 1V Scans
Empty for [485, 560] GHz, filled for [560, 630] GHz
Amplitude (K)
Continuum (K)
[90.5, 91.5] MHz
[97.5, 98.5] MHz

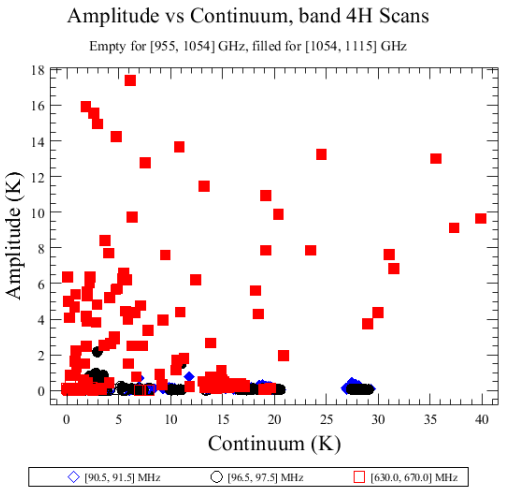

Amplitude vs Continuum, band 2H Scans
Empty for [630, 720] GHz, filled for [720, 800] GHz
Amplitude (K)
Continuum (K)
[91.5, 92.5] MHz
[97.5, 98.5] MHz

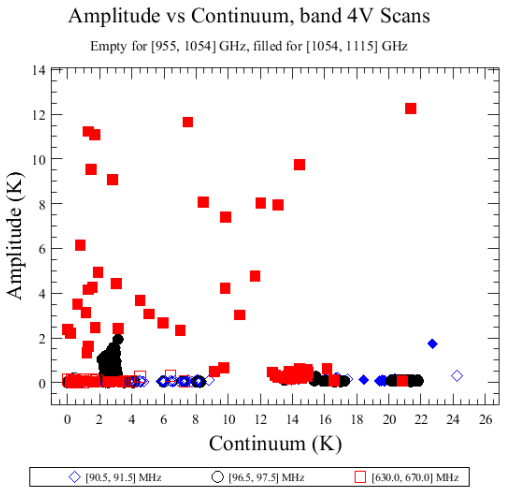

Amplitude vs Continuum, band 2V Scans
Empty for [630, 720] GHz, filled for [720, 800] GHz
Amplitude (K)
Continuum (K)
[91.5, 92.5] MHz
[97.5, 98.5] MHz

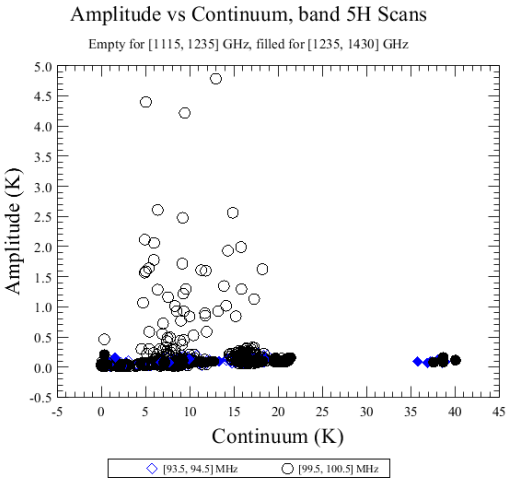

Amplitude vs Continuum, band 3H Scans
Empty for [800, 860] GHz, filled for [860, 955] GHz
Amplitude (K)
Continuum (K)
[89.5, 90.5] MHz
[95.5, 96.5] MHz
[630.0, 670.0] MHz

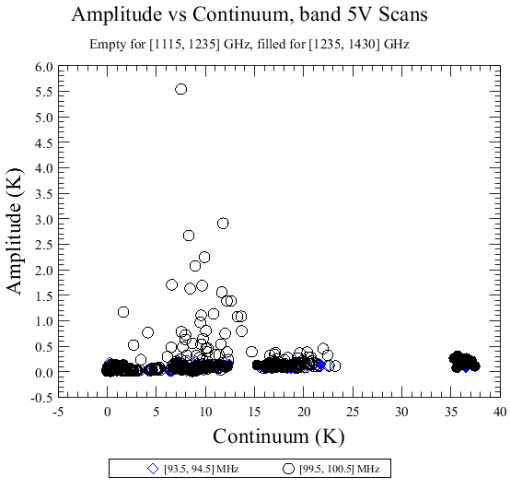

Amplitude vs Continuum, band 3V Scans
Empty for [800, 860] GHz, filled for [860, 955] GHz
Amplitude (K)
Continuum (K)
[89.5, 90.5] MHz
[95.5, 96.5] MHz
[630.0, 670.0] MHz

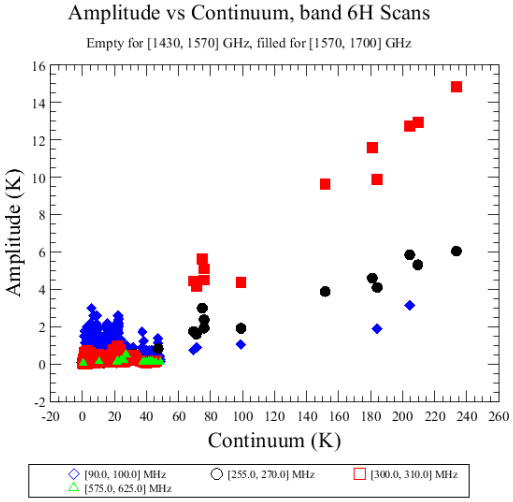
Scans 4,5,6

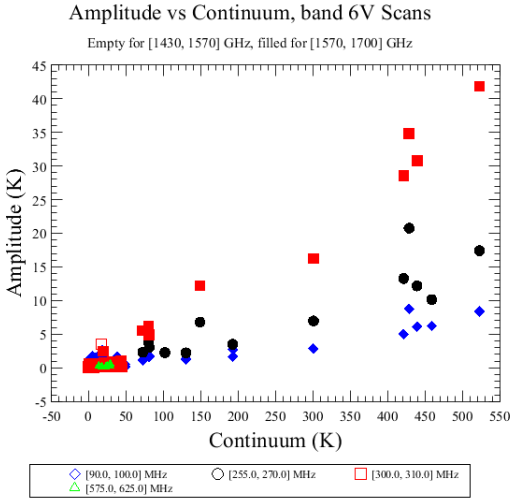

Amplitude vs Continuum, band 4H Scans
Empty for [955, 1054] GHz, filled for [1054, 1115] GHz
Amplitude (K)
Continuum (K)
[90.5, 91.5] MHz
[96.5, 97.5] MHz
[630.0, 670.0] MHz


Amplitude vs Continuum, band 4V Scans
Empty for [955, 1054] GHz, filled for [1054, 1115] GHz
Amplitude (K)
Continuum (K)
[90.5, 91.5] MHz
[96.5, 97.5] MHz
[630.0, 670.0] MHz

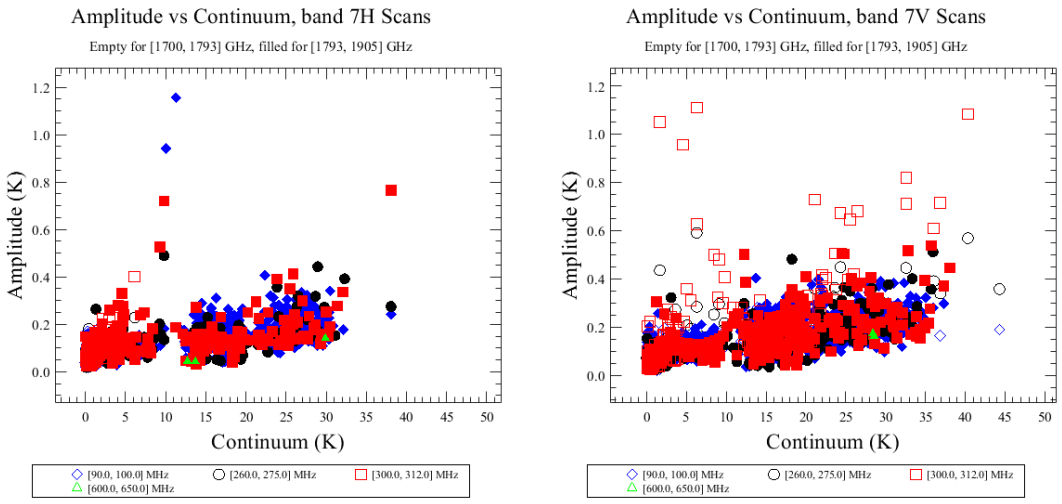

Amplitude vs Continuum, band 5H Scans
Empty for [1115, 1235] GHz, filled for [1235, 1430] GHz
Amplitude (K)
Continuum (K)
[93.5, 94.5] MHz
[99.5, 100.5] MHz


Amplitude vs Continuum, band 5V Scans
Empty for [1115, 1235] GHz, filled for [1235, 1430] GHz
Amplitude (K)
Continuum (K)
[93.5, 94.5] MHz
[99.5, 100.5] MHz


Amplitude vs Continuum, band 6H Scans
Empty for [1430, 1570] GHz, filled for [1570, 1700] GHz
Amplitude (K)
Continuum (K)
[90.0, 100.0] MHz
[255.0, 270.0] MHz
[300.0, 310.0] MHz
[575.0, 625.0] MHz


Amplitude vs Continuum, band 6V Scans
Empty for [1430, 1570] GHz, filled for [1570, 1700] GHz
Amplitude (K)
Continuum (K)
[90.0, 100.0] MHz
[255.0, 270.0] MHz
[300.0, 310.0] MHz
[575.0, 625.0] MHz

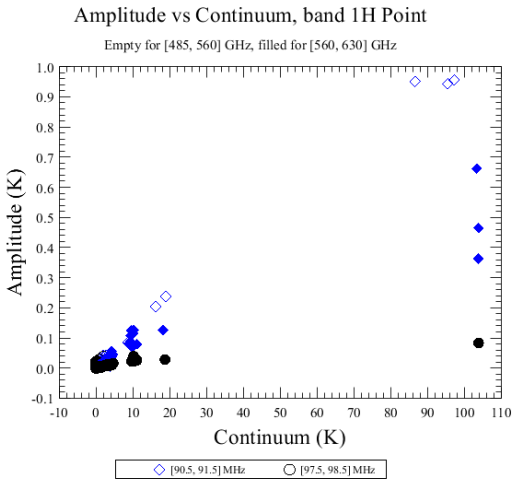
Scans 7

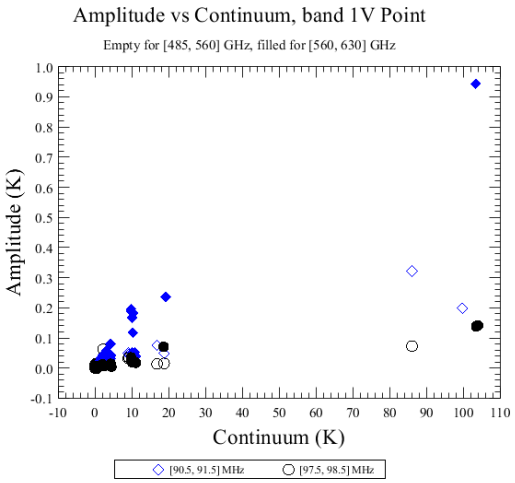


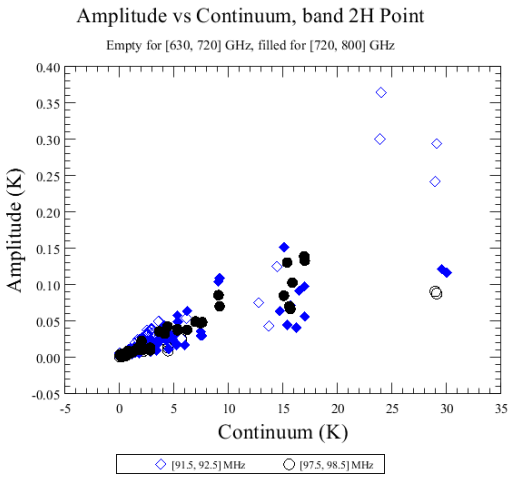
These plots do not show as clear linear behaviour as for planets. Looking at the first bands, there is a vertical line near zero, and then very noisy clusters of dots, which show a progression as continua increases. Although they are not as clean as planets, linear fitting could be useful for this bands.

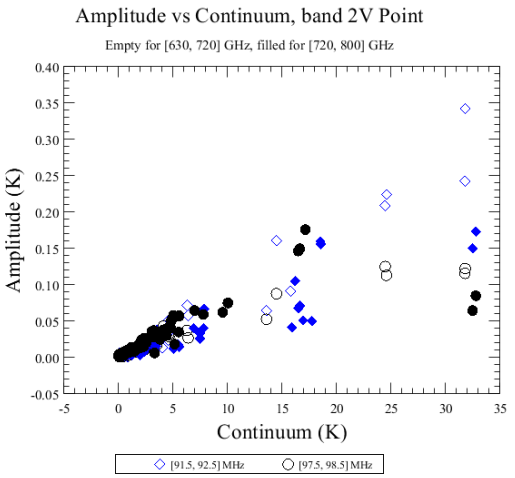
In band 3, the vertical line is located between 4 and 6 K, with a poor linear fitting in lower amplitudes and 4 and 5 are very noisy to extract a linear regression, but in 6 and 7 there are visible slopes. Concretely, in band 6, there are very well defined slopes, but continuum values are so high that they could belong to observations affected by electrical standing waves.

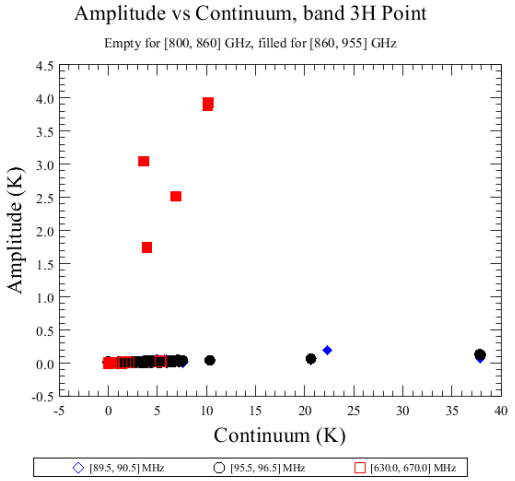
Point 1,2,3

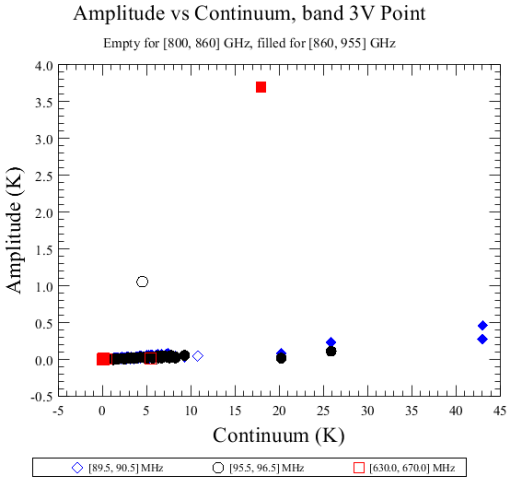

Amplitude vs Continuum, band 1H Point
Empty for [485, 560] GHz, filled for [560, 630] GHz
Amplitude (K)
Continuum (K)
[90.5, 91.5] MHz
[97.5, 98.5] MHz


Amplitude vs Continuum, band 1V Point
Empty for [485, 560] GHz, filled for [560, 630] GHz
Amplitude (K)
Continuum (K)
[90.5, 91.5] MHz
[97.5, 98.5] MHz

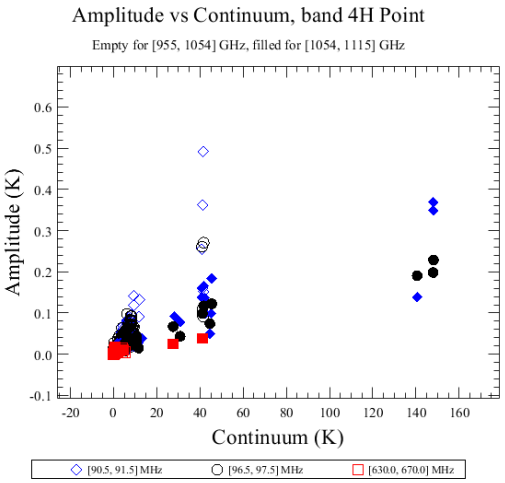

Amplitude vs Continuum, band 2H Point
Empty for [630, 720] GHz, filled for [720, 800] GHz
Amplitude (K)
Continuum (K)
[91.5, 92.5] MHz
[97.5, 98.5] MHz

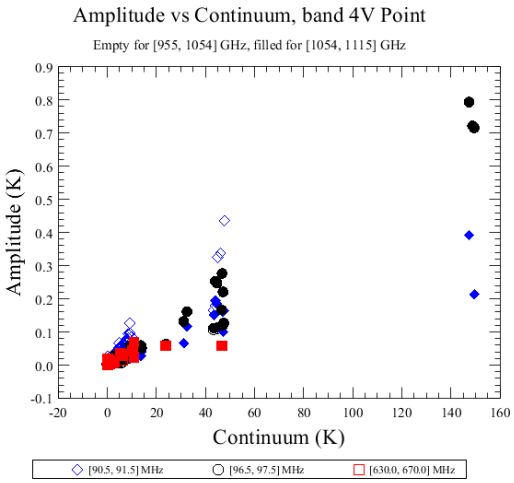

Amplitude vs Continuum, band 2V Point
Empty for [630, 720] GHz, filled for [720, 800] GHz
Amplitude (K)
Continuum (K)
[91.5, 92.5] MHz
[97.5, 98.5] MHz

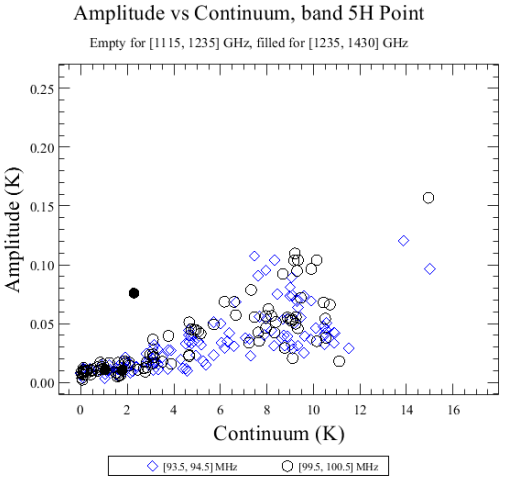

Amplitude vs Continuum, band 3H Point
Empty for [800, 860] GHz, filled for [860, 955] GHz
Amplitude (K)
Continuum (K)
[89.5, 90.5] MHz
[95.5, 96.5] MHz
[630.0, 670.0] MHz

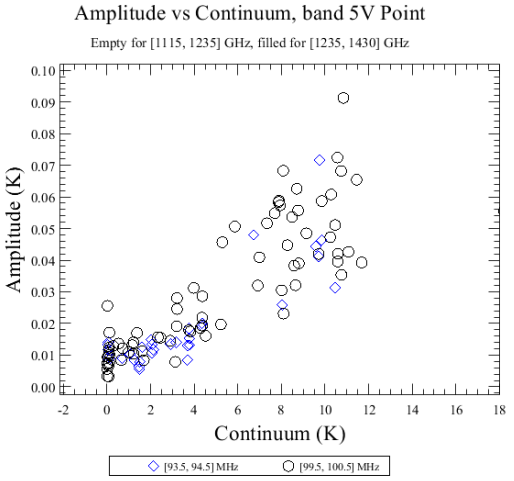

Amplitude vs Continuum, band 3V Point
Empty for [800, 860] GHz, filled for [860, 955] GHz
Amplitude (K)
Continuum (K)
[89.5, 90.5] MHz
[95.5, 96.5] MHz
[630.0, 670.0] MHz

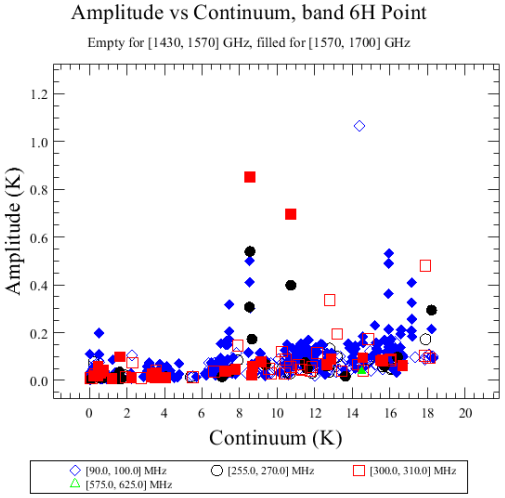
Point 4,5,6

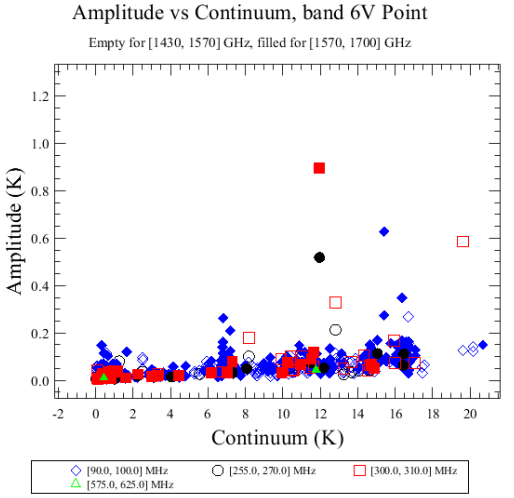

Amplitude vs Continuum, band 4H Point
Empty for [955, 1054] GHz, filled for [1054, 1115] GHz
Amplitude (K)
Continuum (K)
[90.5, 91.5] MHz
[96.5, 97.5] MHz
[630.0, 670.0] MHz


Amplitude vs Continuum, band 4V Point
Empty for [955, 1054] GHz, filled for [1054, 1115] GHz
Amplitude (K)
Continuum (K)
[90.5, 91.5] MHz
[96.5, 97.5] MHz
[630.0, 670.0] MHz

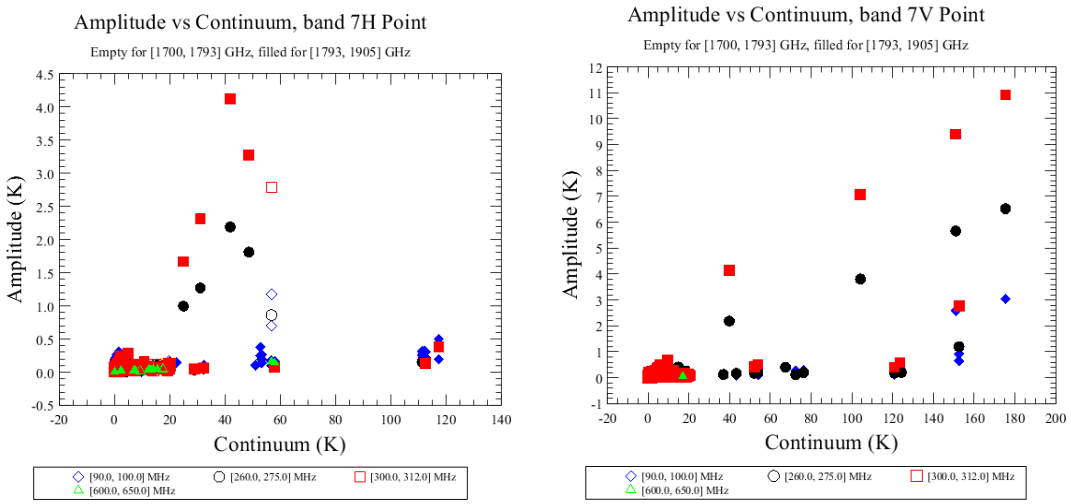

Amplitude vs Continuum, band 5H Point
Empty for [1115, 1235] GHz, filled for [1235, 1430] GHz
Amplitude (K)
Continuum (K)
[93.5, 94.5] MHz
[99.5, 100.5] MHz


Amplitude vs Continuum, band 5V Point
Empty for [1115, 1235] GHz, filled for [1235, 1430] GHz
Amplitude (K)
Continuum (K)
[93.5, 94.5] MHz
[99.5, 100.5] MHz


Amplitude vs Continuum, band 6H Point
Empty for [1430, 1570] GHz, filled for [1570, 1700] GHz
Amplitude (K)
Continuum (K)
[90.0, 100.0] MHz
[255.0, 270.0] MHz
[300.0, 310.0] MHz
[575.0, 625.0] MHz


Amplitude vs Continuum, band 6V Point
Empty for [1430, 1570] GHz, filled for [1570, 1700] GHz
Amplitude (K)
Continuum (K)
[90.0, 100.0] MHz
[255.0, 270.0] MHz
[300.0, 310.0] MHz
[575.0, 625.0] MHz

Point 7



These plots are cleaner than for scans, but worst than for planets. Linear fitting is nice for the first bands (even band 3, with a strong amplitude outliers for the 650 MHz wave compared to the others). Intermediate bands show linear behaviour, but with an important spread (V better than H), and high frequency bands are similar to the scan sample, but less noisy (again we have this huge continua that could belong to observations affected by electrical standing wave, and clusters between 0 and 20 K.

Amplitude vs. Continuum in the 90-92 standing wave (hot load)

Another interesting question is how amplitude and continuum plots change when we focus on particular standing waves. Only two of them (90 and 100 MHz) are present in every mode and band, where 90 MHz amplitude vs continuum plot has better correlations, so only this standing wave is shown here.

Plots are sorted by mode and polarization, using a colour for each band. Dots are filled or not depending on the frequency according to the next table:

(GHz)	A (empty)	B (filled)
Band 1	(485, 560)	(560, 630)
Band 2	(630, 720)	(720, 800)
Band 3	(800, 860)	(860, 955)
Band 4	(955, 1054)	(1054, 1115)
Band 5	(1115, 1235)	(1235, 1430)
Band 6	(1430, 1570)	(1570, 1700)
Band 7	(1700, 1793)	(1793, 1905)

Table 2: Subranges of frequencies used in plots

The aim of this plots it is to give an overview of this standing wave in every band avoiding details. In band 5 there is not enough observations in 5B to split data in sub-bands so it is shown directly, and band 6 and 7 are too noisy to put them here.

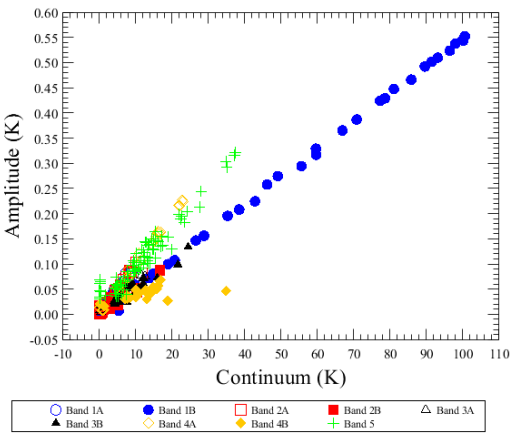
Summarizing results:

- Planets: Cleanest plots (not surprising). Linear relationships are obvious and there is one for each sub-band. In some cases lines overlap, so it is reasonable to think that there will be common slopes to some bands. Looking at polarizations, it is remarkable that 1A slope appears only in V. That is because in H is much lower and is hidden inside the cluster located in low continua. 1B slope looks the same for H and V, and for band 5 the slope decreases significantly from H to V. Bands 2 and 3 show similar slopes, decreasing from H to V both at the same rate. Band 4A does not show an important variation from H to V, and for 4B slopes are not very clear.

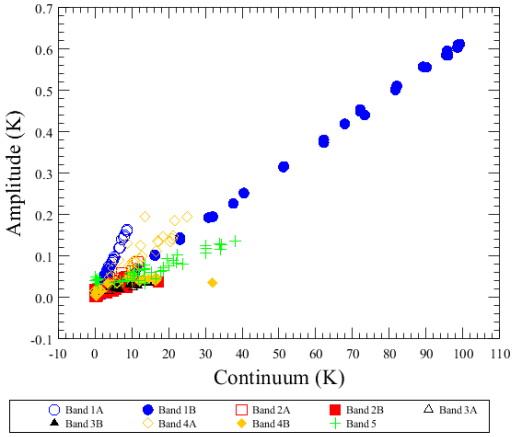
- Scans: The worst ones (again, not surprising). Very noisy to extract information. With the present data, we cannot consider good linear correlations inside sub-bands. In H it is possible to see that band 4B shows at least two slopes, but we do not have enough information for splitting ranges.

- Point: Linear relationships are good, although are not so clean as in planets. Nothing unexpected, because we can think about it as a bigger sample than planets with similar characteristics.

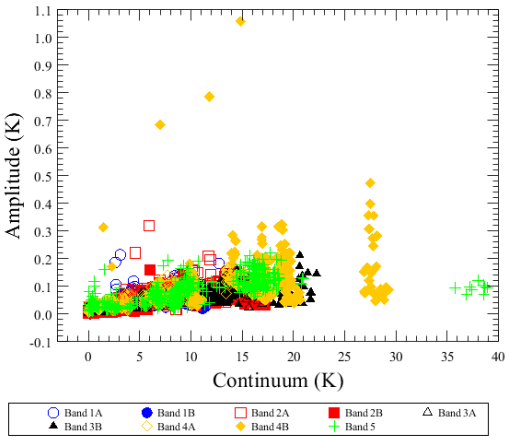
90-92 MHz standing wave in H for Planets



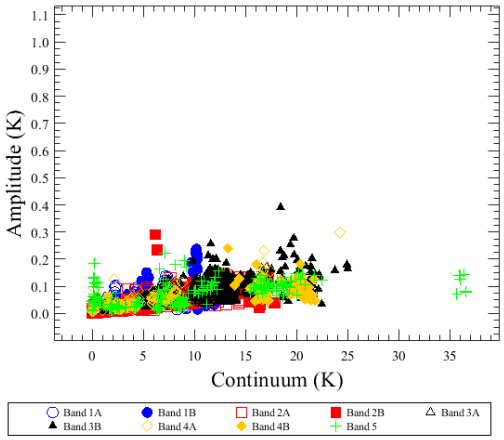
90-92 MHz standing wave in V for Planets



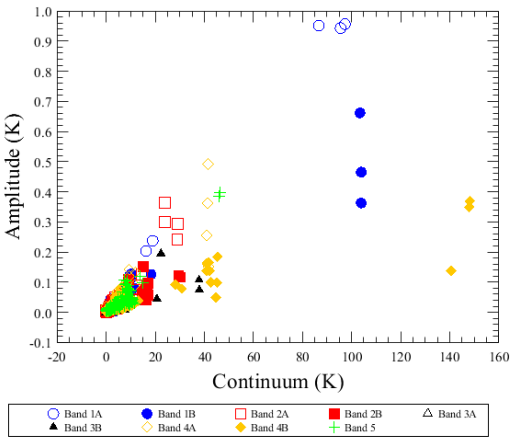
90-92 MHz standing wave in H for Scans



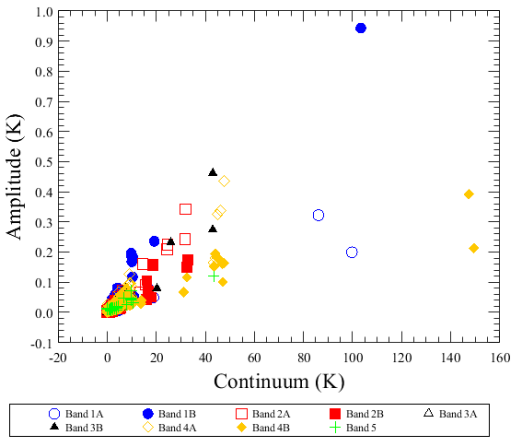
90-92 MHz standing wave in V for Scans



90-92 MHz standing wave in H for Point



90-92 MHz standing wave in V for Point



3.2 Slopes vs. Period

Using a linear regression fit, a slope is obtained for each range of period/frequency in amplitude vs. continuum relationship. Results are shown in a table for each mode, where A and B corresponds to different frequency ranges (see Table 1), and plotted over periods by band and frequency. The correlation factor (r^2) is also given as a figure of merit of the fit. Correlation factor of 1.0 correspond to cosas with only 2 points in the sample, and cannot be trusted.

Planets

Band	Period	A	r²	B	r²
1H	[88.5,89.5]	0.001557888446	0.9149	0.001404531728	0.9971
	[90.5,91.5]	0.009560870433	0.9880	0.005451374282	0.9996
	[97,98]	0.004734215711	0.8368	0.000799864955	0.8368
1V	[88.5,89.5]	-	-	0.000882420281	0.8297
	[90.5,91.5]	0.018530497830	0.9974	0.006216164999	0.9996
	[97,98]	0.001235249685	0.8386	0.000906748450	0.9900
2H	[91.5,92.5]	0.009129613231	0.9786	0.004089920495	0.9500
	[98,99]	0.001459977588	0.9733	0.002130175768	0.8718
2V	[91.5,92.5]	0.006091756129	0.9791	0.001952814422	0.8035
	[98,99]	0.003210082332	0.7352	0.003849496126	0.8640
3H	[89.5,90.5]	0.005889792868	0.9958	0.004448675577	0.9379
	[95.5,96.5]	0.002636421563	0.9729	0.004416245165	0.8275
	[630,670]	0.000085334153	0.0553	0.001970422101	0.7243
3V	[89.5,90.5]	0.000972875720	0.9953	0.001413807100	0.7950
	[95.5,96.5]	0.001616613773	1.0000	0.003189604183	0.7669
	[630,670]	-	-	0.001684121182	0.6315
4H	[90.5,91.5]	0.009671357127	0.9973	0.001045824836	0.5412
	[96.5,97.5]	-	<0	0.001404940870	0.8200
	[630,670]	-	-	-	<0
4V	[90.5,91.5]	0.007370646178	0.9395	0.000517507981	0.4759
	[96.5,97.5]	0.002042394980	0.9503	0.002832793878	0.8227
	[630,670]	0.001568372869	0.8913	0.001001013740	0.7635
5H	[93.5,94.5]	0.007841162939	0.9786	-	<0
	[99.5,100.5]	0.003729267636	0.8115	0.002081084921	0.9898
5V	[91.5,92.5]	0.002673793197	0.9203	-	-
	[98,99]	0.003344724920	0.6813	-	<0
6H	[90,100]	0.002088743874	0.7658	0.002644959279	0.6850
	[255,270]	0.001145207248	0.4624	0.001806773012	0.8353
	[300,310]	0.003773404075	0.8811	0.002294018331	0.8195
	[575,625]	0.003319385552	1.0000	0.001845923916	0.6935
6V	[90,100]	0.003887772165	0.8254	0.003181045490	0.7793
	[255,270]	-	-	0.001210041297	0.8883
	[300,310]	0.002717916317	0.9981	0.001687462713	0.7596
	[575,625]	-	-	-	-
7H	[90,100]	0.003596762681	0.7941	0.002209071663	0.4383
	[260,275]	-	-	0.010797699290	0.4779
	[300,312]	0.011942205310	0.8202	0.007376198795	0.2702
	[600,650]	0.002390162794	0.9266	0.003293262602	0.7589
7V	[90,100]	0.002776246054	0.7779	0.002818507038	0.4940
	[260,275]	0.002128389006	0.8943	0.003310764851	0.2649
	[300,312]	0.002612889307	0.8581	0.011680122470	0.3859
	[600,650]	-	-	-	-

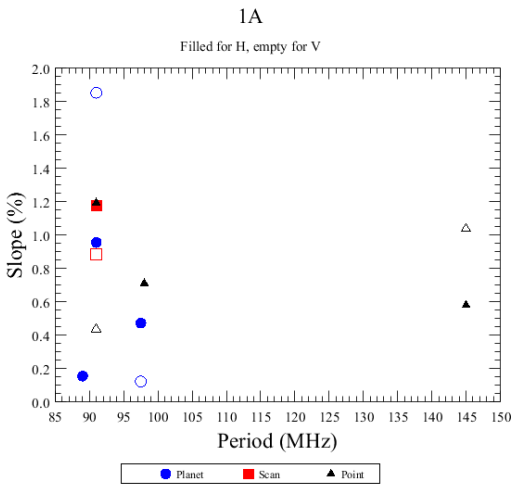
Scan

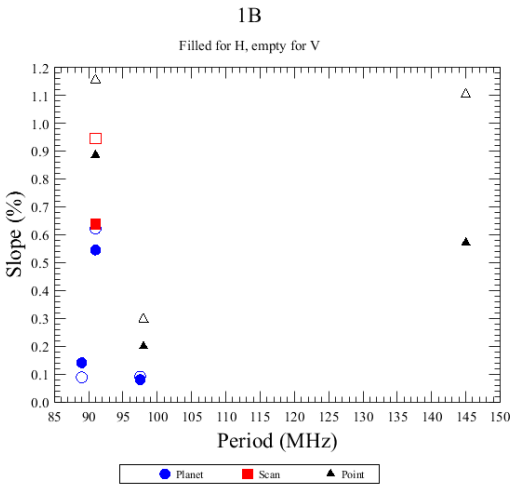
Band	Period	A	r^2	B	r^2
1H	[90.5,91.5]	0.011756086720	0.8414	0.006374187764	0.8326
1V	[90.5,91.5]	0.008865034626	0.7583	0.009452380534	0.7306
2H	[91.5,92.5]	0.007621522457	0.7616	0.005170386010	0.7334
	[97.5,98.5]	<0	<0	0.003840399056	0.5263
2V	[91.5,92.5]	0.006261628017	0.8295	0.004702339164	0.6258
	[97.5,98.5]	<0	<0	0.005137079963	0.7057
3H	[89.5,90.5]	0.004963944963	0.8225	0.004228156230	0.7222
	[95.5,96.5]	0.003769750868	0.7409	<0	<0
	[630,670]	<0	<0	0.005085512717	0.2962
3V	[89.5,90.5]	0.006208702880	0.8446	0.006308800657	0.7329
	[95.5,96.5]	0.002073109637	0.5224	<0	<0
	[630,670]	0.001222543620	0.0285	-	<0.1
4H	[90.5,91.5]	0.009364383811	0.8509	0.005797729332	0.4563
	[96.5,97.5]	0.004859975787	0.4700	0.001404940870	0.8200
	[630,670]	<0	<0	0.095927153348	0.2131
4V	[90.5,91.5]	0.007859692092	0.8045	0.005637397381	0.2742
	[96.5,97.5]	0.000307668435	0.0389	<0	<0
	[630,670]	0.011563076363	0.3147	<0	<0
5H (A<0.3)	[93.5,94.5]	0.006845005452	0.7798	0.000329124114	0.1459
	[99.5,100.5]	0.007763112891	0.6714	0.001265213398	0.3887
5V (A<0.3)	[91.5,92.5]	0.003300871953	0.4960	0.001592010415	0.5839
	[98,99]	0.005976598352	0.6632	0.002736421910	0.6714
6H (C<60)	[90,100]	-	<0.3	-	<0.3
	[255,270]	-	<0.1	0.005820514041	0.5000
	[300,310]	0.026095497820	0.6500	<0	<0
	[575,625]	-	-	<0	<0
6V (C<60)	[90,100]	-	<0.3	-	<0.3
	[255,270]	-	<0.3	0.004207378049	0.4500
	[300,310]	0.136281022500	0.7800	-	<0.3
	[575,625]	-	-	0.014398342010	0.5600
6H (C>60)	[90,100]	-	-	0.014637797430	0.9400
	[255,270]	-	-	0.024739117020	0.9600
	[300,310]	-	-	0.061620899030	0.9800
6V (C>60)	[90,100]	-	-	0.015223694010	0.9200
	[255,270]	-	-	0.032088987690	0.8900
	[300,310]	-	-	0.075502864630	0.9800
7H	[90,100]	0.004736777970	0.2200	0.004726706173	0.6600
	[260,275]	0.014772433630	0.4800	0.004953027104	0.6100
	[300,312]	0.036268368860	0.6800	0.004349334211	0.4600
7V	[90,100]	0.005497009112	0.7900	0.005106589073	0.7400
	[260,275]	0.007722462220	0.7000	0.006193639889	0.7000
	[300,312]	0.011836258410	0.6200	0.006143421589	0.6700

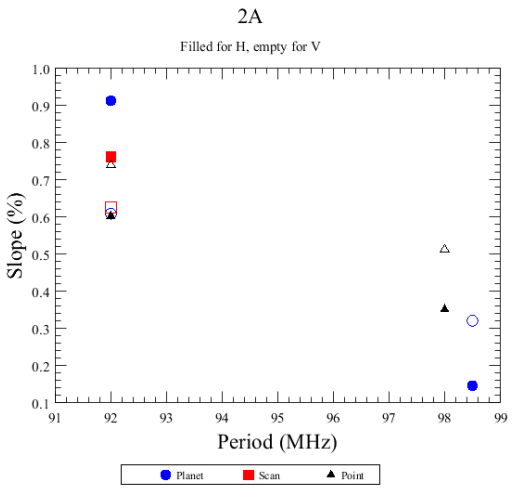
Point

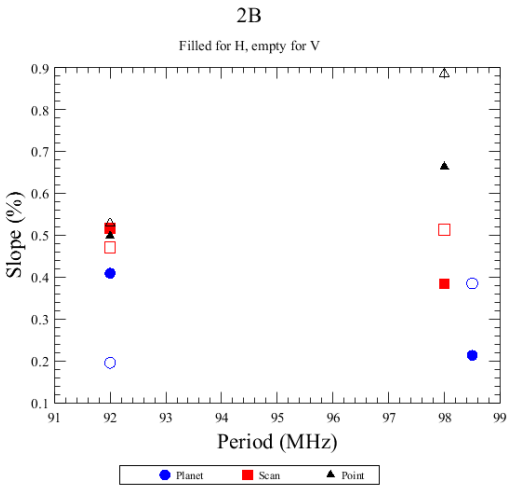
Band	Period	A	r^2	B	r^2
1H	[90.5,91.5]	0.011934518231	0.9843	0.008860273283	0.9360
	[97.5,98.5]	0.007106182128	0.5335	0.001994512997	0.9171
	[144.5,145.5]	0.005797883575	0.8602	0.005718669099	0.9800
1V	[90.5,91.5]	0.004372932853	0.8070	0.011539130180	0.8676
	[97.5,98.5]	0.001305047940	0.4455	0.002968448489	0.9289
	[144.5,145.5]	0.010380152594	0.9301	0.011030760242	0.5498
2H	[91.5,92.5]	0.006030086993	0.8401	0.004987257187	0.8250
	[97.5,98.5]	0.003517455565	0.8749	0.006638151283	0.9525
2V	[91.5,92.5]	0.007403465410	0.9051	0.005282687617	0.8766
	[97.5,98.5]	0.005123444879	0.9413	0.008852127693	0.9755
3H	[89.5,90.5]	0.005539571052	0.8791	0.003818550260	0.7819
	[95.5,96.5]	0.003217475776	0.7207	0.004385271758	0.9015
	[630,670]	0.004317031352	0.9115	0.007637025359	1.0000
3V	[89.5,90.5]	0.007234714071	0.8737	0.006012215818	0.8277
	[95.5,96.5]	0.035030182768	0.2564	0.005033656945	0.8653
	[630,670]	0.000486752664	0.1724	-	-
4H	[90.5,91.5]	0.007506330599	0.8403	0.002486151467	0.8423
	[96.5,97.5]	0.006674170048	0.8397	0.002694341219	0.8881
	[630,670]	0.000564463156	0.2055	0.000435853481	0.1756
4V	[90.5,91.5]	0.006412510227	0.8559	0.002889890324	0.8785
	[96.5,97.5]	0.003117413181	0.8303	0.004437798813	0.9459
	[630,670]	0.002544663626	0.7361	0.003788093152	0.8564
5H	[93.5,94.5]	0.005183261878	0.7490	-	-
	[99.5,100.5]	0.006541649601	0.8184	-	-
5V	[91.5,92.5]	0.003897113097	0.8525	-	-
	[98,99]	0.004159585939	0.8483	-	-
6H	[90,100]	0.003102108641	0.6119	0.008480631403	0.6026
	[255,270]	0.003722203479	0.5364	0.009576687224	0.4287
	[300,310]	0.008245873985	0.4788	0.009273337974	0.2572
6V	[90,100]	0.003244108131	0.5293	0.006035882428	0.5810
	[255,270]	0.002874399580	0.2912	0.008379836549	0.4710
	[300,310]	0.010342732164	0.5176	0.012872345036	0.3840
7H (C<25K)	[90,100]	0.004573632418	0.8468	0.001535537799	0.2838
	[260,275] A > 0.02 K	0.004236297120	0.9338	0.036724258442	0.8440
	[260,275] A < 0.02 K	-	-	0.002564405937	0.6495
	[300,312] A > 0.03 K	0.004710179501	0.9082	0.063123139719	0.8587
	[300,312] A < 0.03 K	-	-	0.003172771997	0.6190
	[600,650]	0.003124514384	0.9024	0.002167049653	0.8708
7V (C<25K)	[90,100]	0.004009478598	0.7154	0.002111003127	0.3452
	[260,275] A > 0.01 K	0.022141935057	0.9940	0.019411841585	0.8573
	[260,275] A < 0.01 K	0.002943730834	0.7901	0.002969168769	0.7061
	[300,312] A > 0.03 K	0.003893678503	0.5603	0.057412918111	0.9333
	[300,312] A < 0.03 K	-	-	0.004143248196	0.5826

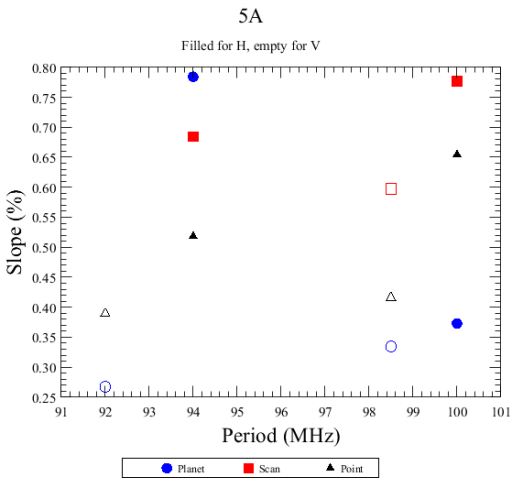
Bands 1,2,5

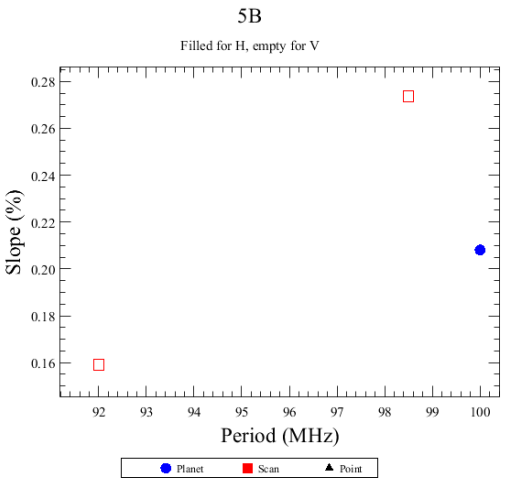

1A
Filled for H, empty for V
Slope (%)
Period (MHz)
Planet
Scan
Point


1B
Filled for H, empty for V
Slope (%)
Period (MHz)
Planet
Scan
Point


2A
Filled for H, empty for V
Slope (%)
Period (MHz)
Planet
Scan
Point

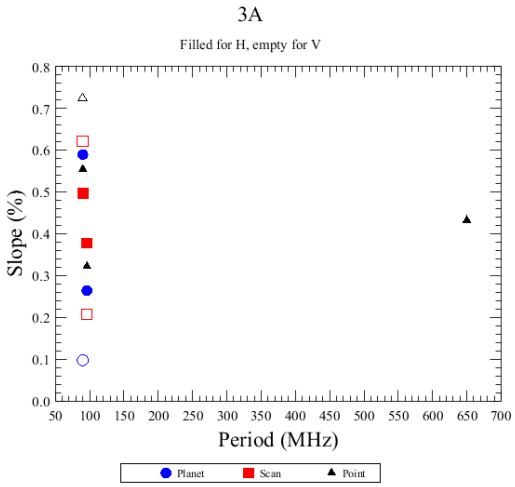

2B
Filled for H, empty for V
Slope (%)
Period (MHz)
Planet
Scan
Point

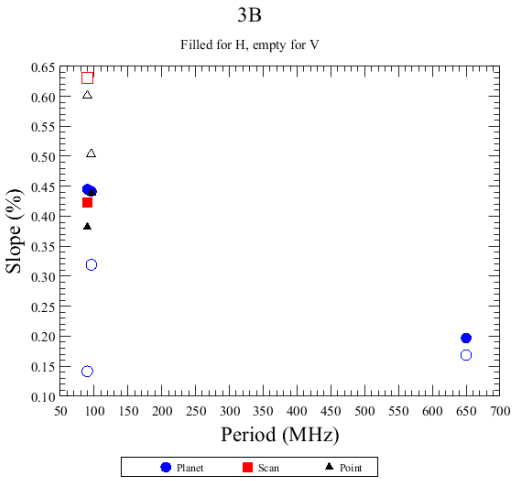

5A
Filled for H, empty for V
Slope (%)
Period (MHz)
Planet
Scan
Point

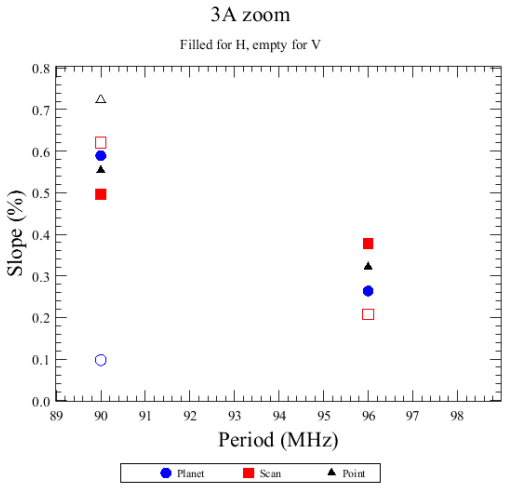

5B
Filled for H, empty for V
Slope (%)
Period (MHz)
Planet
Scan
Point

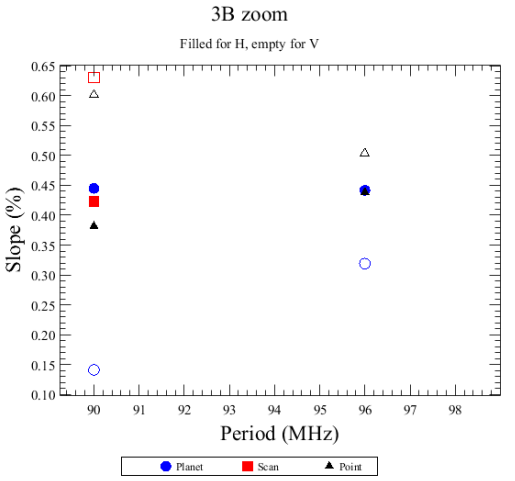
Bands 3 and 4 are shown in a different page because they are the only bands who have defined slopes in the 650 MHz period. When plotting every slope in this kind of plots, 90 and 100 MHz overlap and is difficult to extract information about how do they change. For this reason zoom plots are shown, focusing in these standing waves.

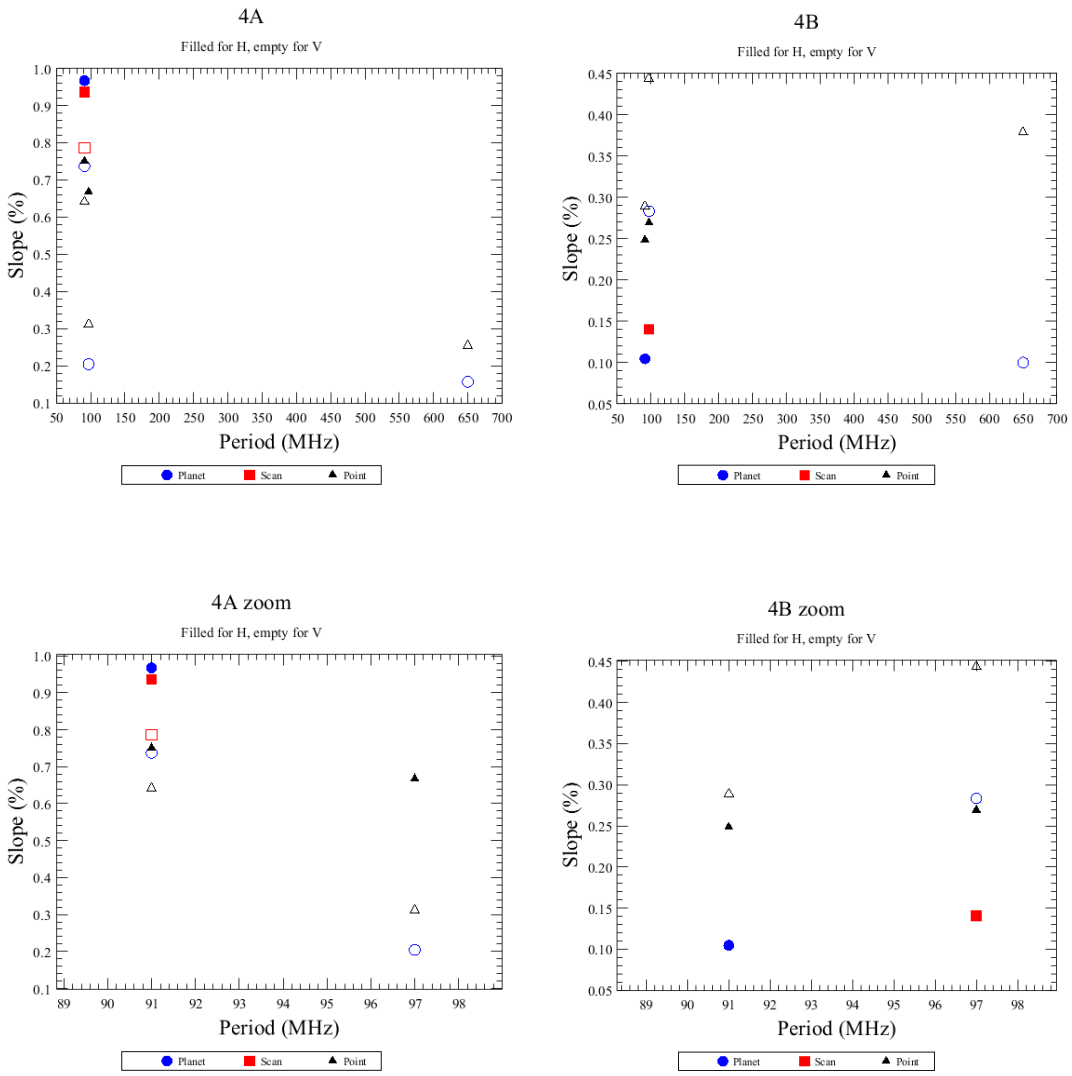
Bands 3,4











The plots show the behaviours of slopes in different periods (standing waves). Only the first five bands are shown, considering:

- Slopes with $r^2 = 1$ correspond to lines with two points, which are not considered in the analysis due to the small size of the sample.
- Missing values in the tables correspond to negative slopes, slopes with very low correlation factors or very small size samples, not being interesting for a deeper analysis.
- Bands 6 and 7 are very noisy to extract clear and well defined slopes, so are not shown in plots.
- Band 5 in scan is split in two ranges of amplitude because it is possible to see in the plot two different regimes inside a given period.
- Band 6 in scan is split in two ranges of continuum because continua higher than 60 K are present in outlier observations. Band 7 in point is split in two ranges of amplitude for the same reason.

4 Conclusion

Summarizing all the results, we can conclude:

- From all samples, the best calibrator is planets and the worst scans. Slopes from planets have very good correlation factors, specially in lower bands. For higher bands (6 and 7) this approach is not very accurate due to high noise and the unaccuracy of linear fitting.
- 90 and 100 MHz standing waves are present in every sample and band. Electrical standing waves become important in every mode for the last two bands, and 650 MHz period is only important in intermediate bands (3 and 4). For point mode there is another standing wave (144 MHz) whose origin is unknown.
- For 90 MHz standing wave there is no general behaviour between band (and sub-band) and slope. Each set of band, sub-band and polarization has his own characteristics.
- The tendency of the slopes when increasing period is different for every band and mode, and have to be studied separately.