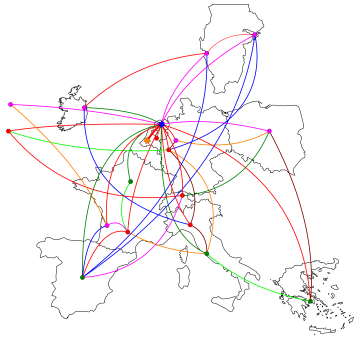
Sideband ratio assessment for HIFI

R. Higgins, D. Teyssier
and the SBR working group

Herschel calibration workshop,
March 27th 2013



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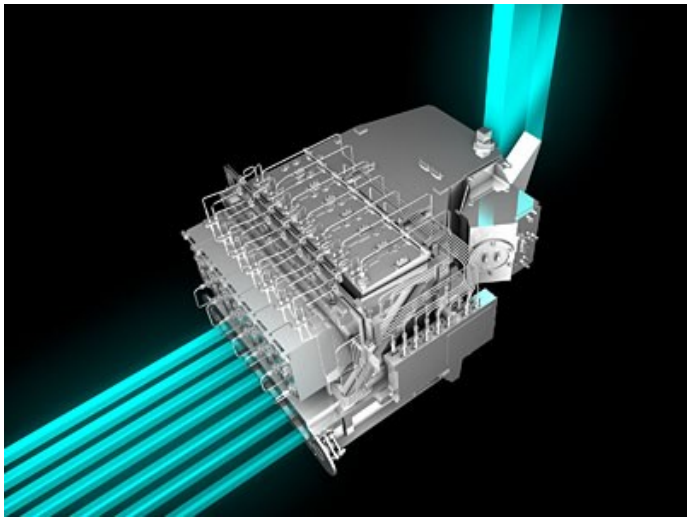
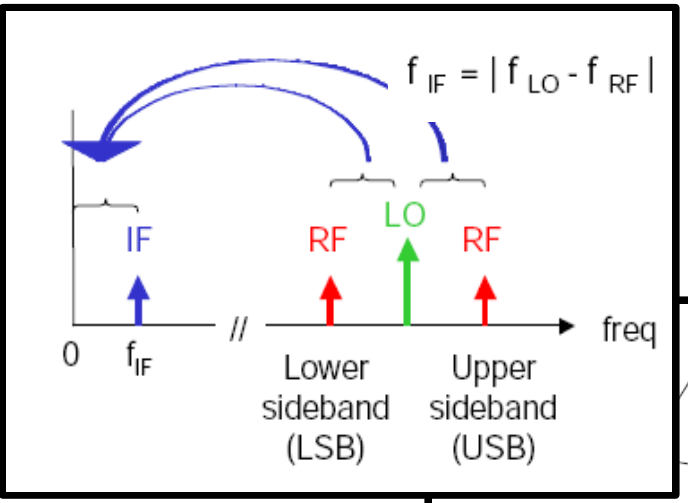
Overview

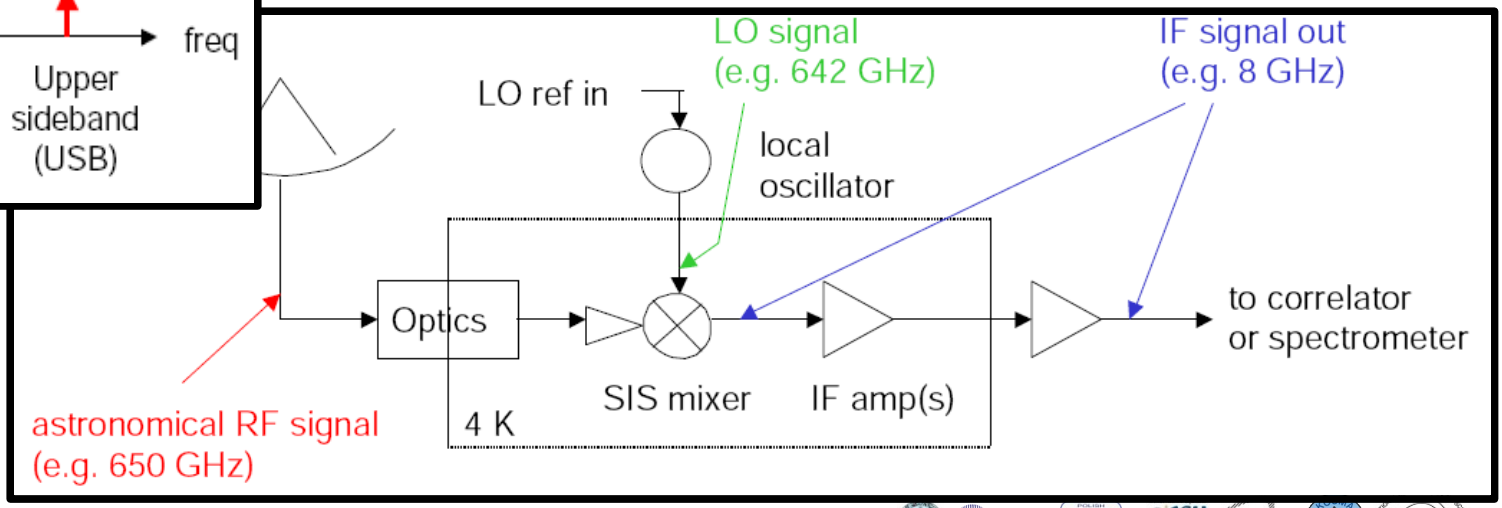
- Heterodyne principle
- What is side band ratio?
- Efforts to measure side band ratio
- Effects of side band ratio as seen in data
  - 12CO (5-4) in band 1b
  - Water line at 557GHz
  - Lower edge of band 2a
- Plans for Post-ops
- Effect on overall Error budget

Heterodyne principle

- Using Heterodyne techniques gives HIFI very high spectral resolution, R=lambda/delta_lambda = 10^6







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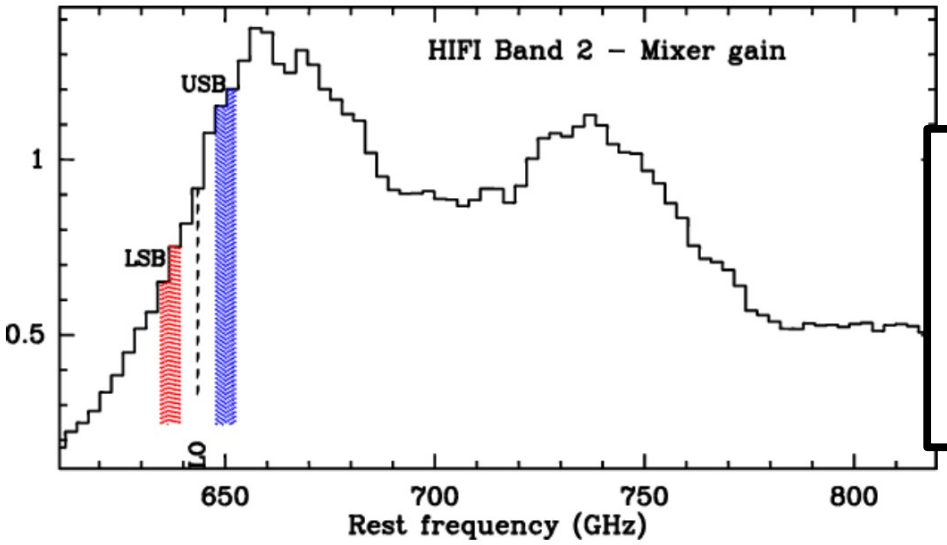
What is side band ratio?

- HIFI observes simultaneously an upper and lower side band. The intensity is calibrated by observing a hot and cold load. Since the gain across the 2 sideband isn't necessarily equal this results in one side band been dominant over the other. This relationship is described by the side band ratio



$$R = \frac{G_{usb}}{G_{lsb}}, \quad G_{ssb} = \frac{G_{usb}}{G_{lsb} + G_{usb}} = \frac{R}{1+R}$$

Calibration equation, alma memo 442

$$J_{S,ssb} - J_{R,ssb} = \frac{c_S - c_R}{\eta_{sf}\eta_l\gamma^l_{rec}G_{ssb}} = \frac{\eta_h + \eta_c - 1}{\eta_{sf}\eta_l G_{ssb}} \frac{c_S - c_R}{c_{hot} - c_{cold}} (J_{h,eff} - J_{c,eff})$$

G_ssb is the fraction of double side band response that comes from the upper side band

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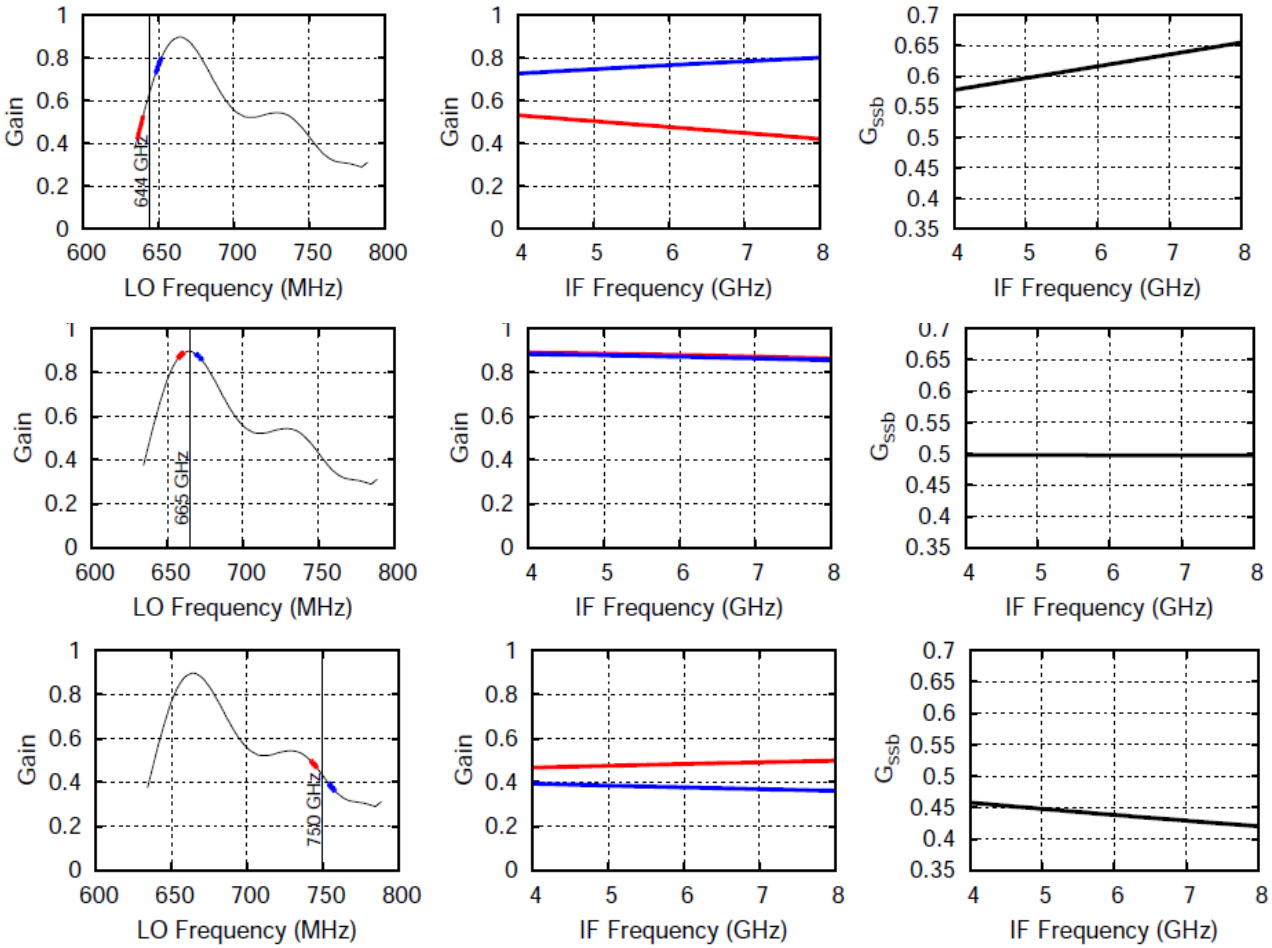
What is side band ratio?



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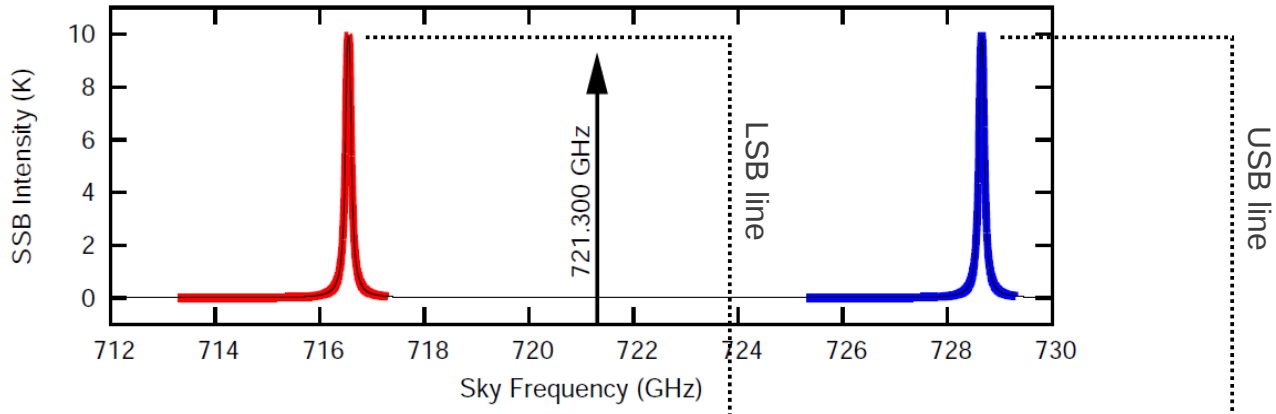
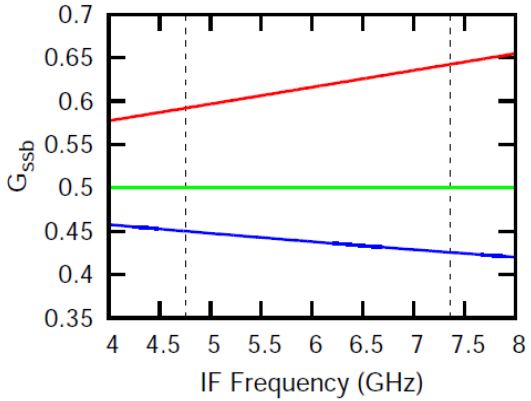
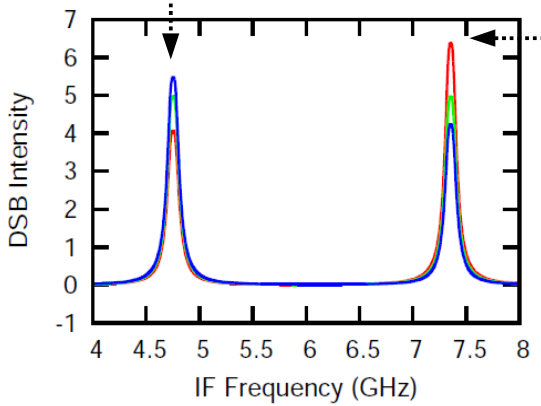
What is side band ratio?



(a) OCS spectra shown between 712 and 730 GHz. The resulting upper and lower side band are highlighted in blue and red respectively when observing with an LO frequency of 721.3 and an IF bandwidth from 4-8 GHz





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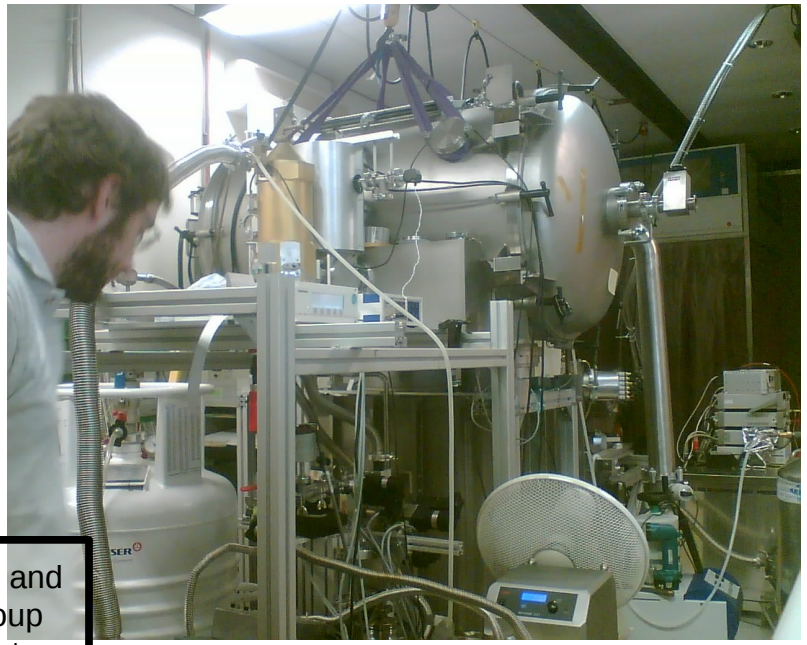
Efforts to measure side band ratio

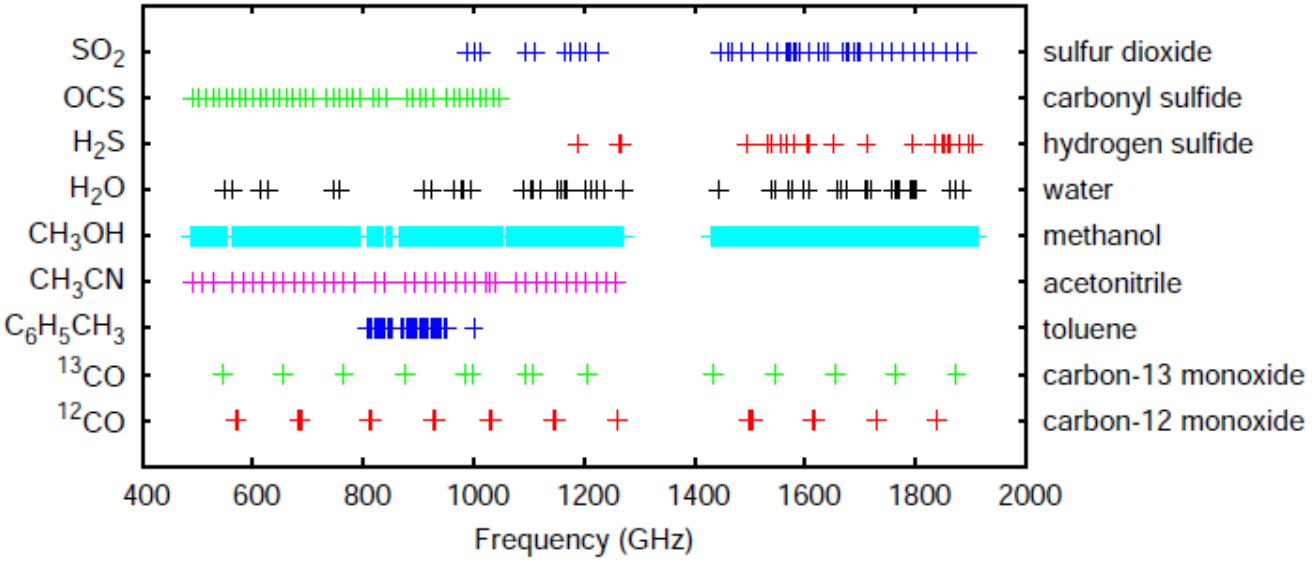
- By observing know gases in the gas cell, the instrument performance can be extracted
- A suite of tools were developed by the author to model and extract the instrument performance by comparing the expected output and the measured output



Gas cell was designed and built by the LERMA group in Paris and operated at SRON, Groningen

Gas cell analysis: spectrum model generation

- By observing lines with strong spectral line emission the side band ratio can be extracted. The gas cell path length was chosen to maximize the line intensity observed
- Lines which saturate in the gas cell conditions are particularly useful in determining the side band ratio



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spectrum model generation : 12CO

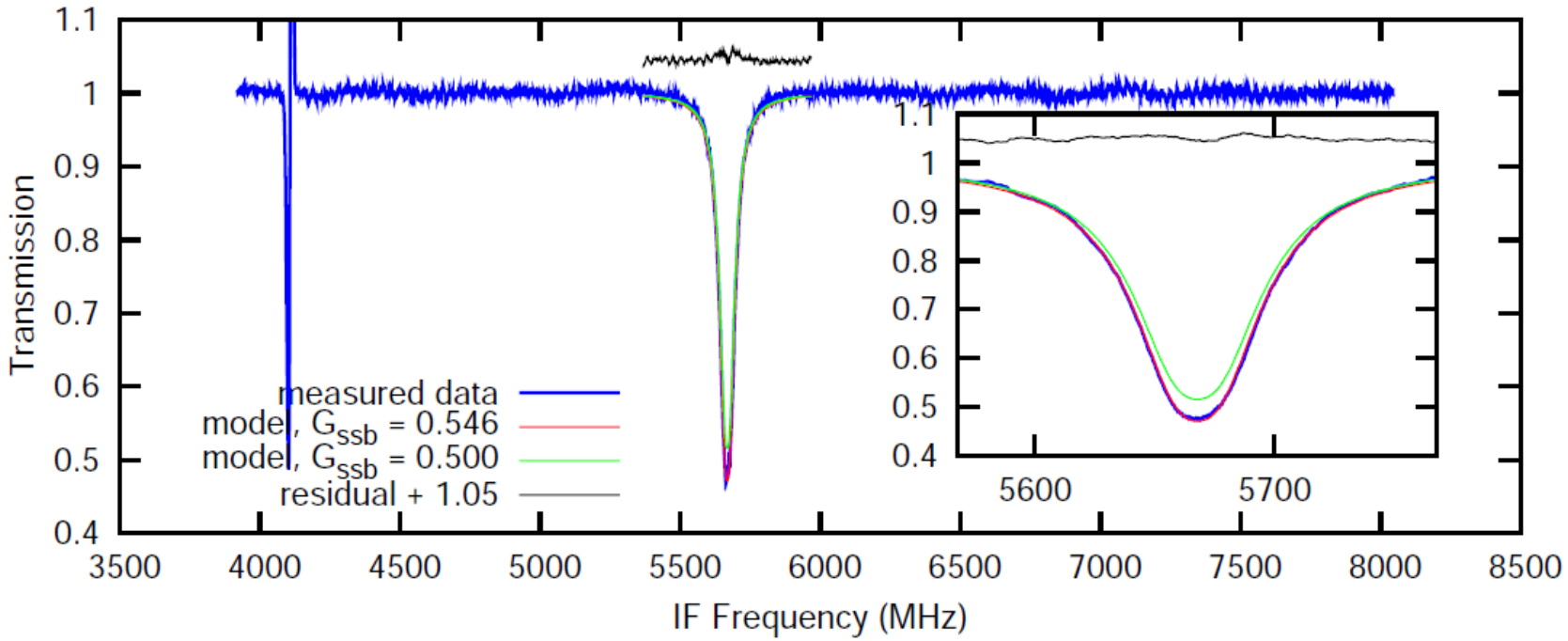
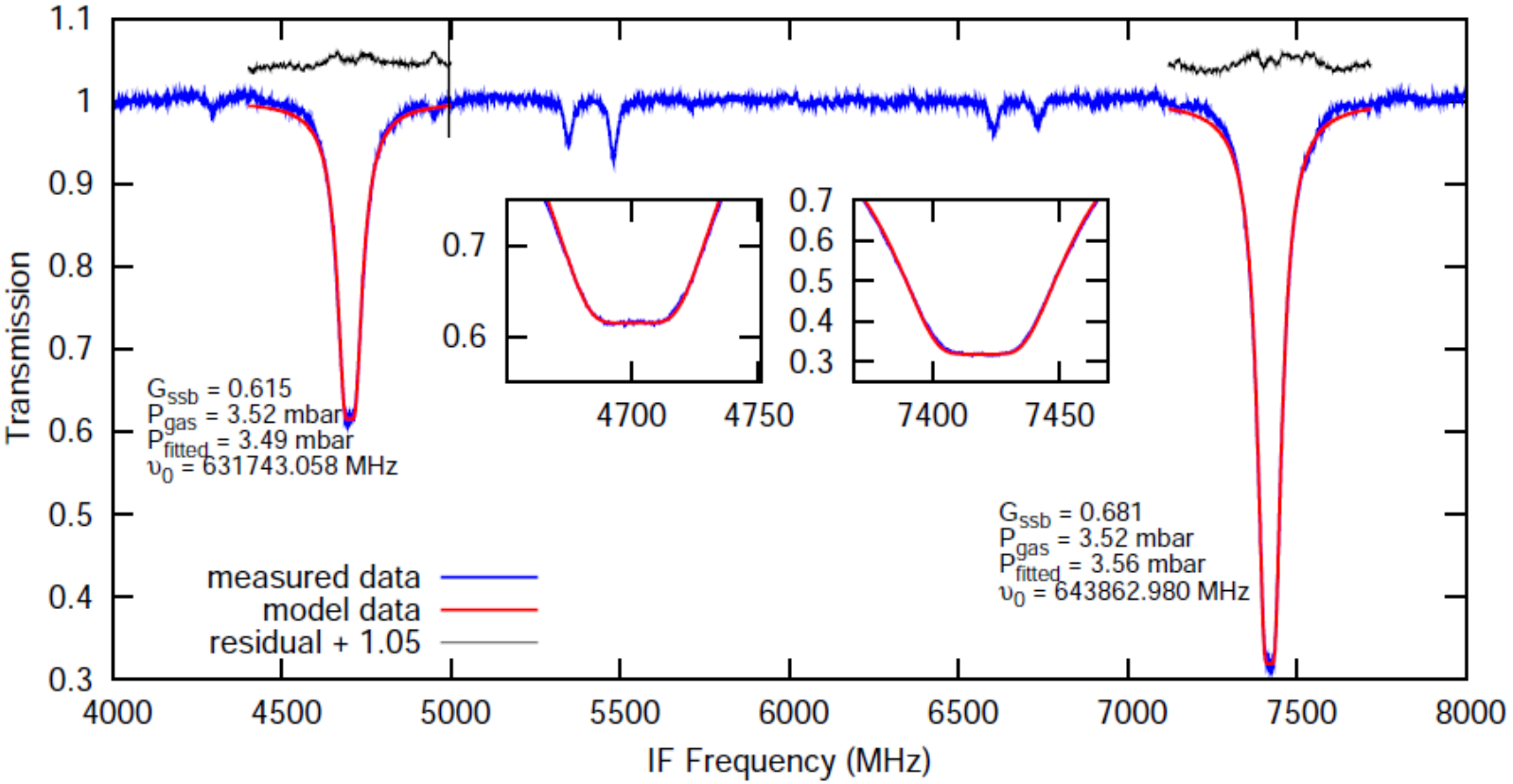


Figure 5.4: Double side band model spectra for a ^{12}CO gas cell observation at a gas cell pressure of 5.54mbar. Spectrum was taken at an LO frequency 570.6 GHz. The model spectra for side band gain balanced state is shown in green (G_{ssb} =0.5). The fitted profile with a side band ratio of 0.546 is plotted in red. The residual to the fitted data is shown in black with an offset.

spectrum model generation: OCS



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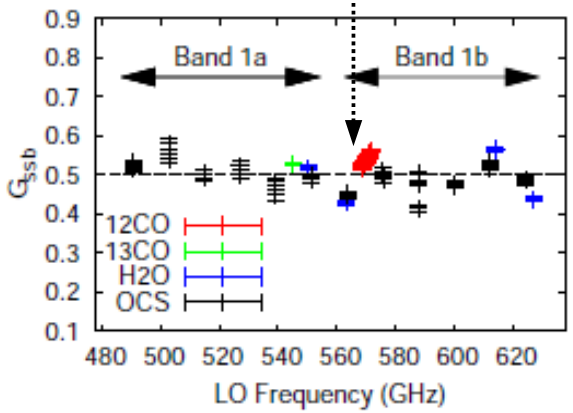
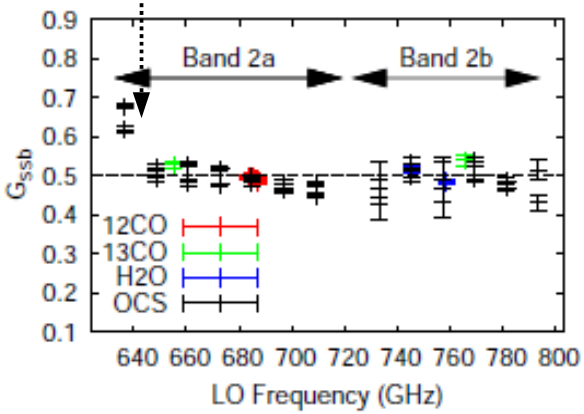
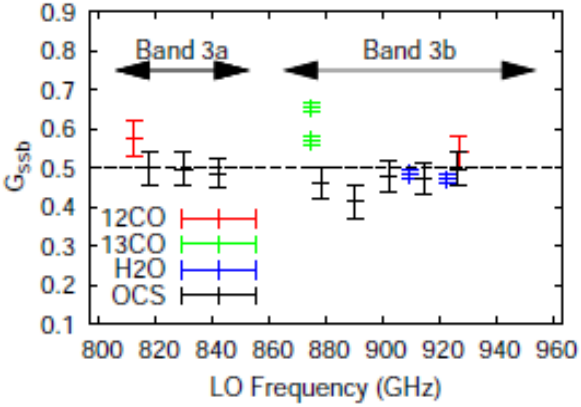
Gascell results summary

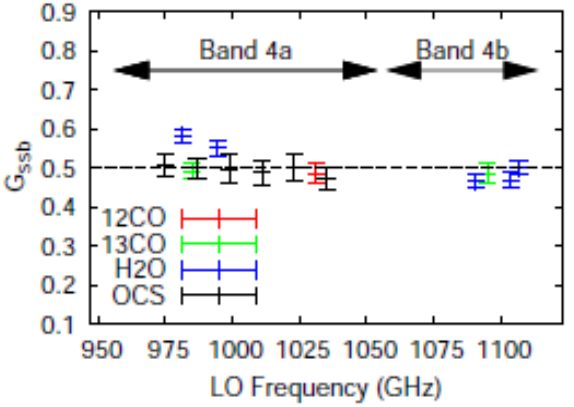
Regions of interest

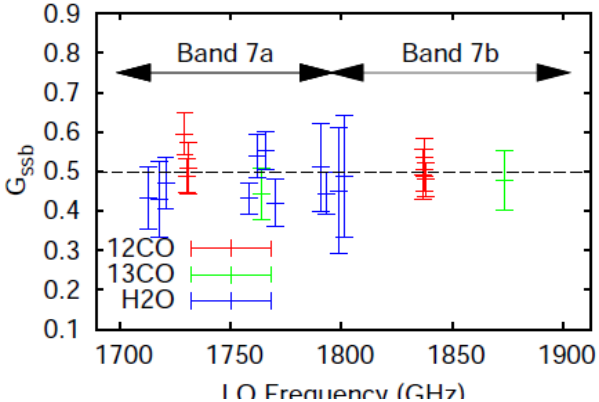


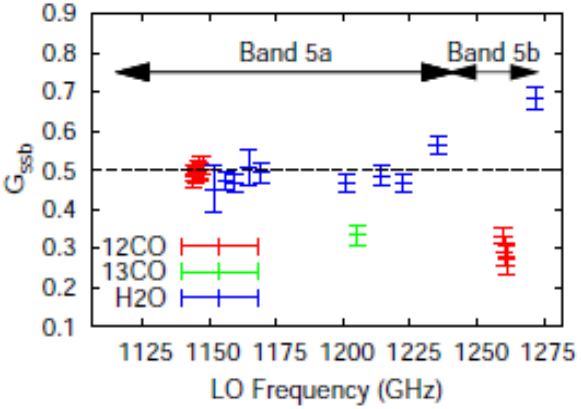


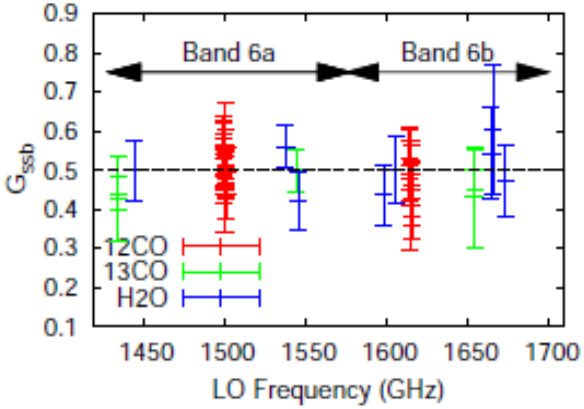
Extracted side band ratio for H mixer, see Thesis of Ronan Higgins for more information



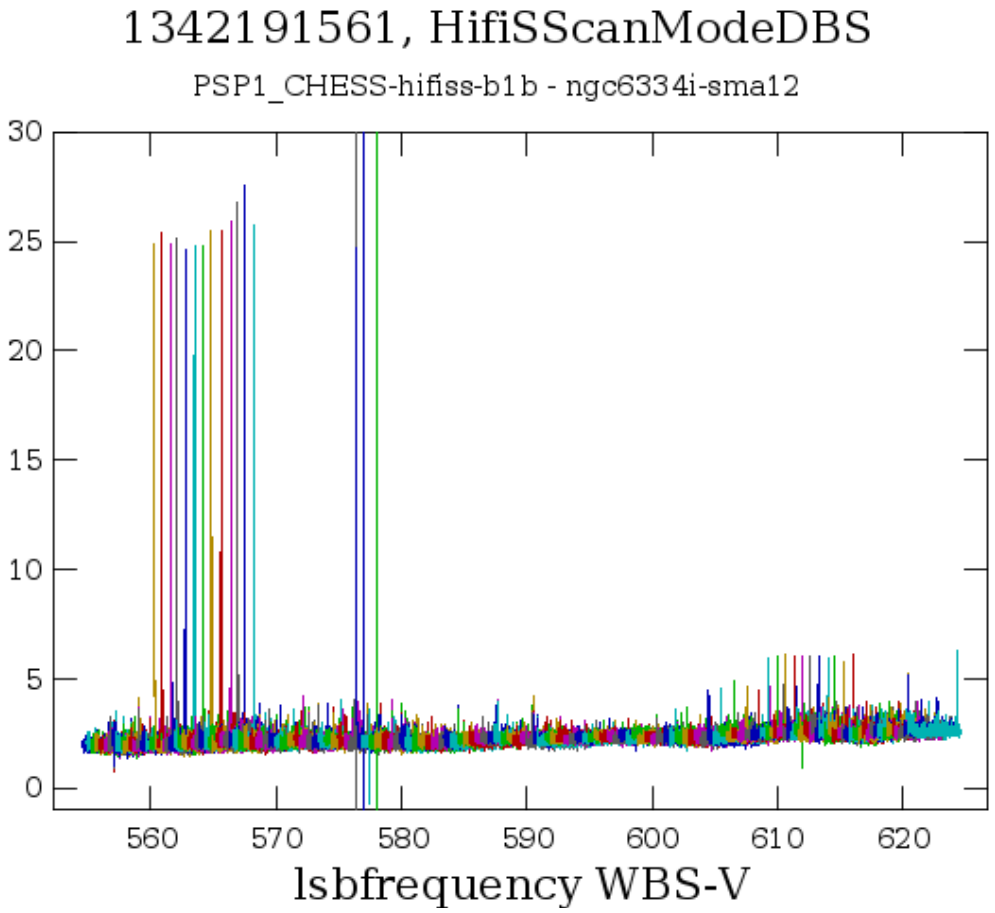






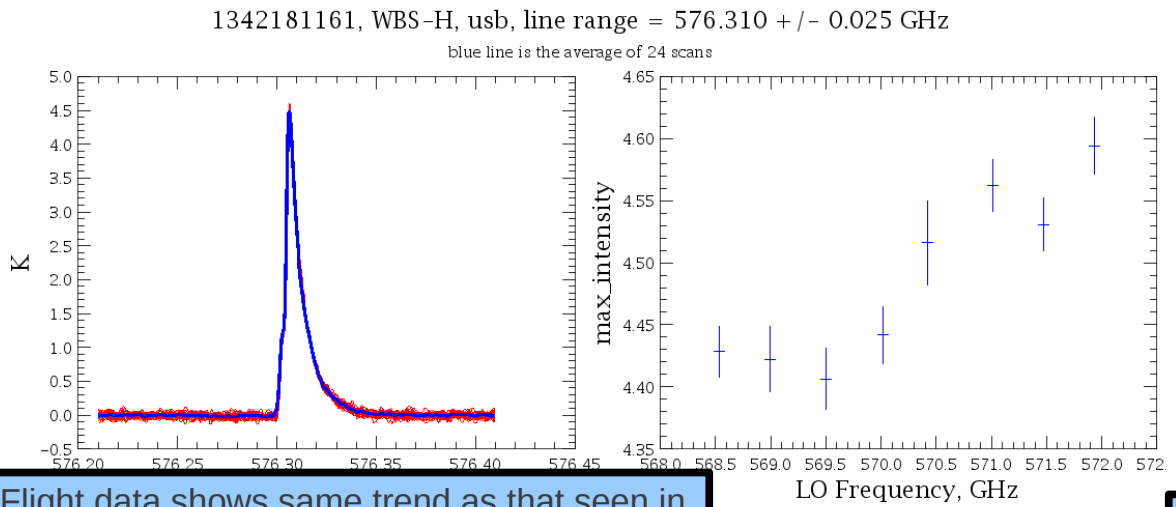


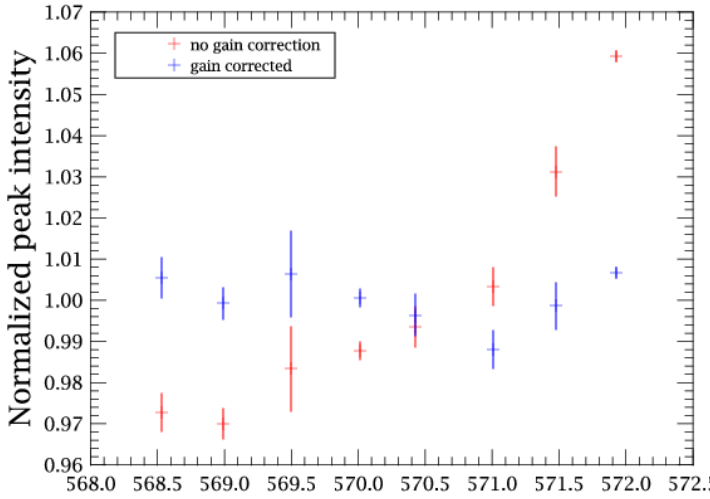
Know regions of side band ratio imbalance: 12CO (5-4)



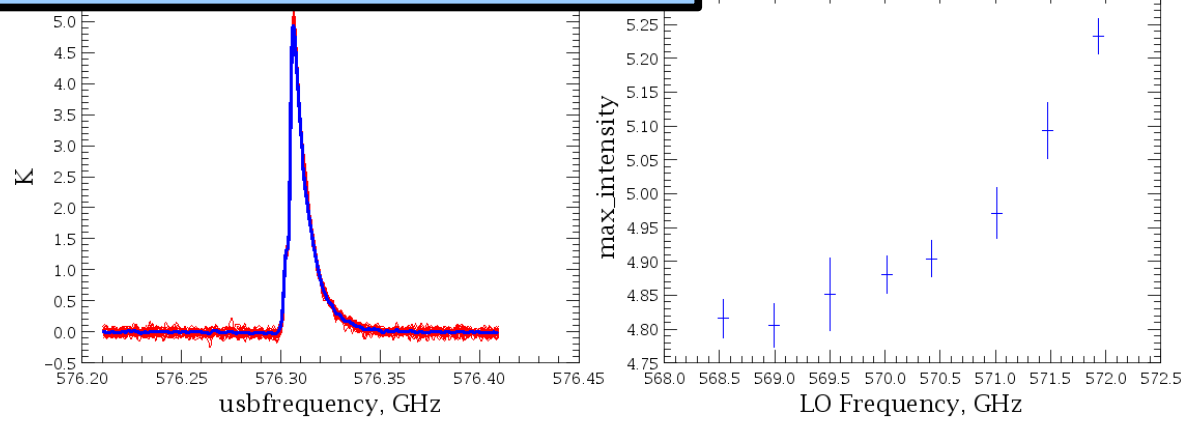
- Evidence of side band ratio can be seen in spectral scans.
- As a spectral line is observed at different LO frequencies it moves through the IF
- If a side band ratio imbalance is present at that frequency range, the line intensity will vary
- In this example an obvious variation in 12CO line intensity is seen
- This was trend also observed in the gas cell test campaign

Known regions of side band ratio imbalance: 12CO (5-4)

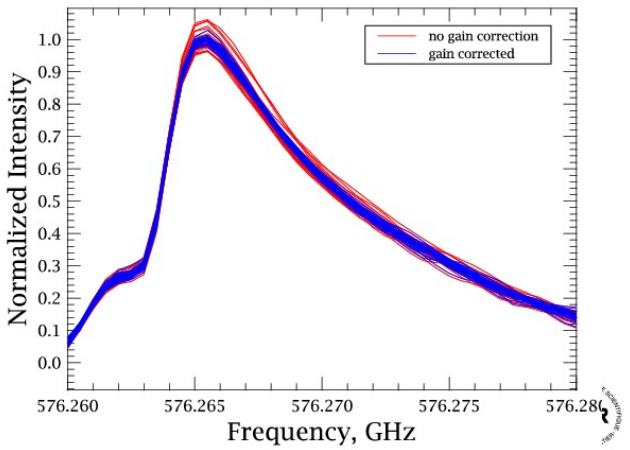




Flight data shows same trend as that seen in gas cell data, depending on IF frequency line can be 4 – 16% over estimated



Applying gains from gas cell reduces scatter in flight data from 10% to 3%



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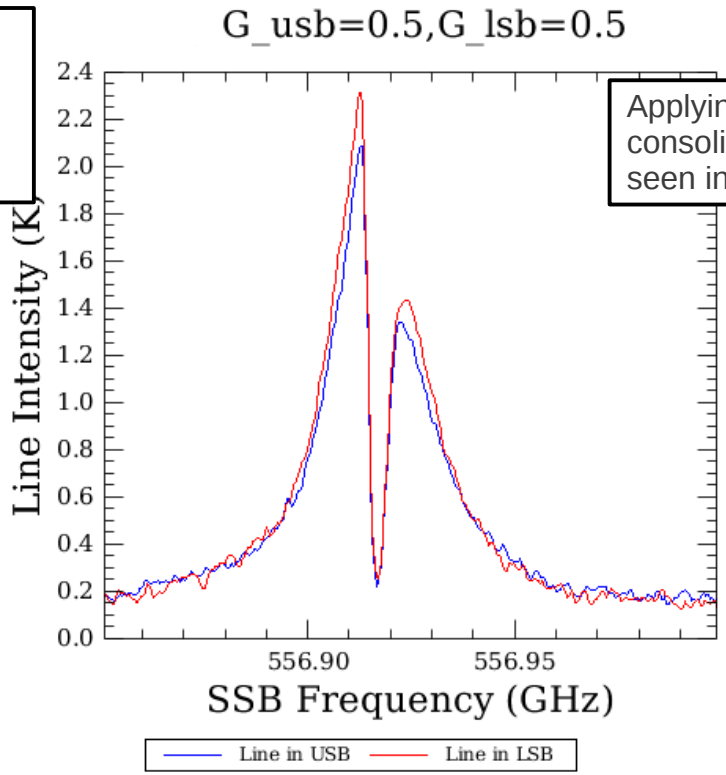
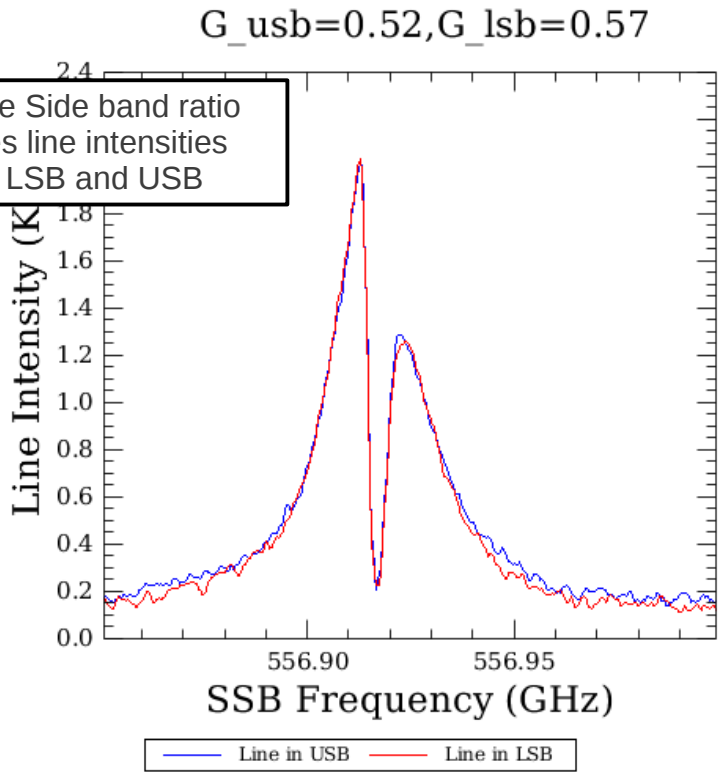
Known regions of side band ratio imbalance: H2O 557GHz

- Evidence of side band ratio can also be seen when the line intensities measured in the upper and lower side band are different

In this example, one might average the USB and LSB profile and still have an over estimated line intensity



Applying the Side band ratio consolidates line intensities seen in the LSB and USB



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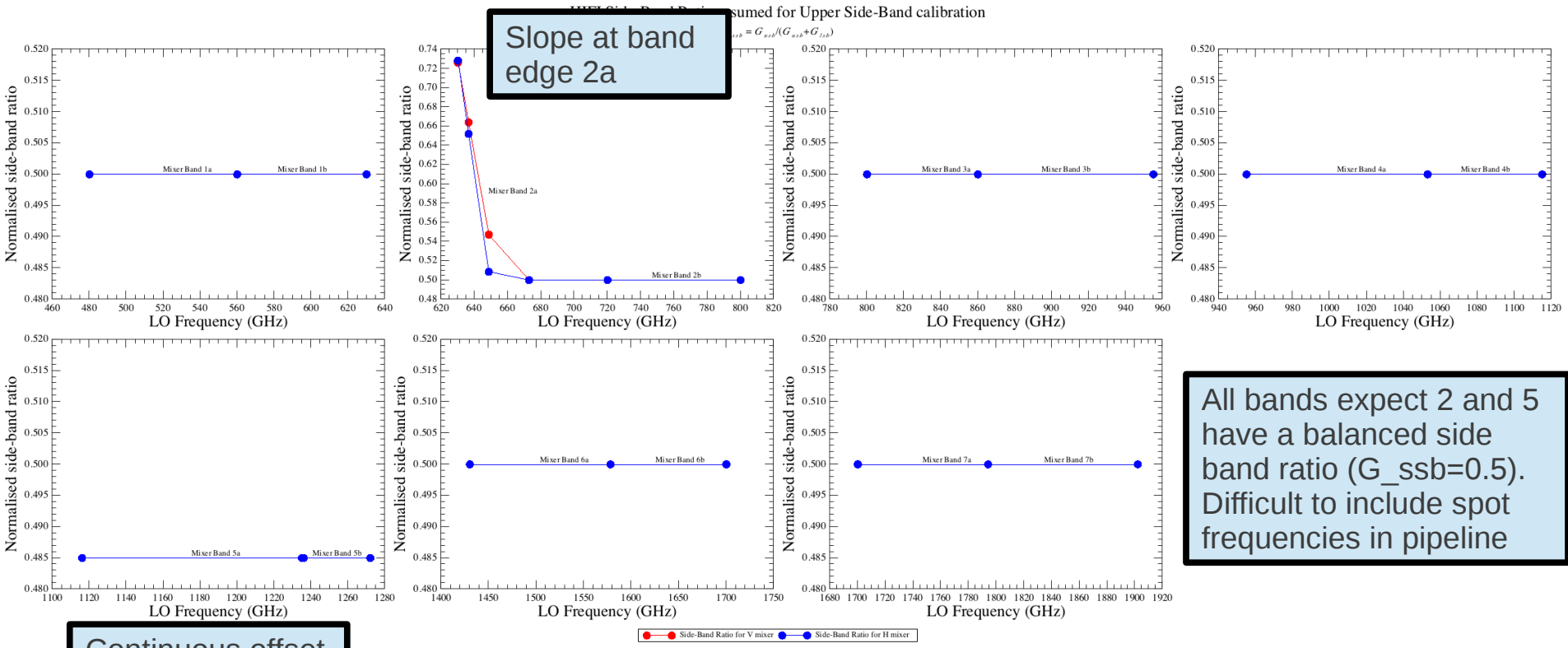
Shortcomings of gas cell test campaign

- Gas cell data provides our most complete picture of the sideband ratio
- Gas cell data was taken during the ground test campaign when we were still learning to operate the instrument
- The frequency coverage during the gas cell test campaign wasn't optimum, degree of variation in side band ratio wasn't expected
- Instrument setup wasn't optimum,
  - Diplexer model in band 3 and 4 wasn't optimum and led to slopes in the side band gain across the IF band
  - HEB bands weren't stable during ground campaign leading to poor quality data
  - LO purities problems in band 3 and 5

Current status of side band ratio in pipeline



Slope at band edge 2a

All bands expect 2 and 5 have a balanced side band ratio (G_ssb=0.5). Difficult to include spot frequencies in pipeline

Continuous offset in band 5, also seen in gascell

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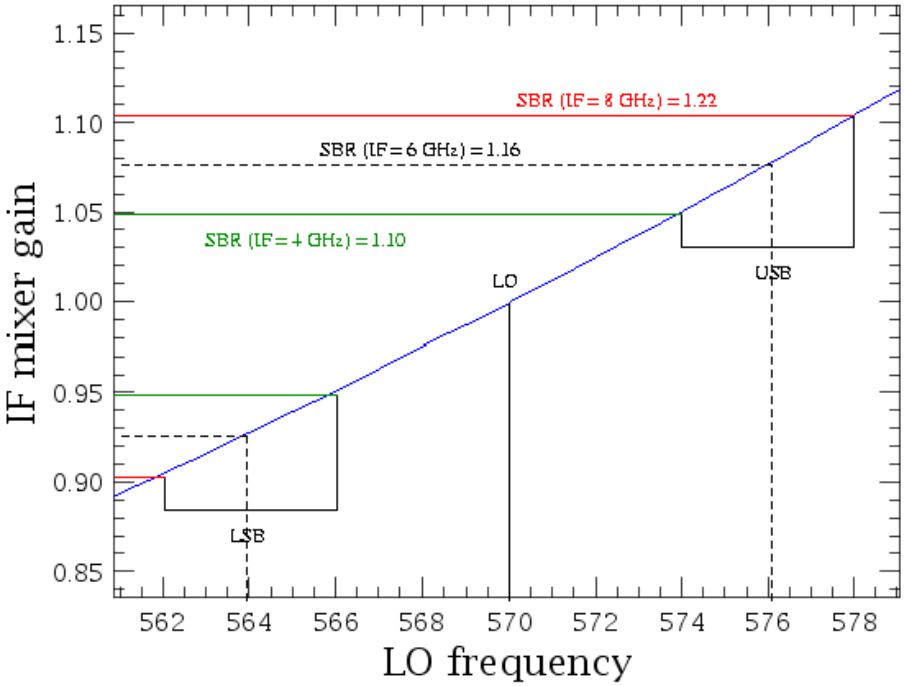
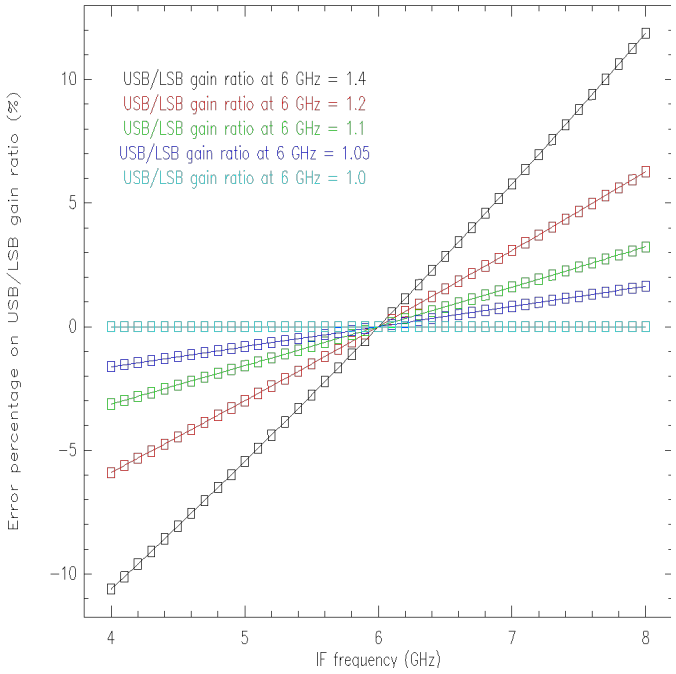
Way forward in post ops: update pipeline task

- Update DoSidebandGain pipeline task to reflect our better knowledge of side band gain variation across the IF band. Currently it's a fixed value, adapt to include frequency dependence





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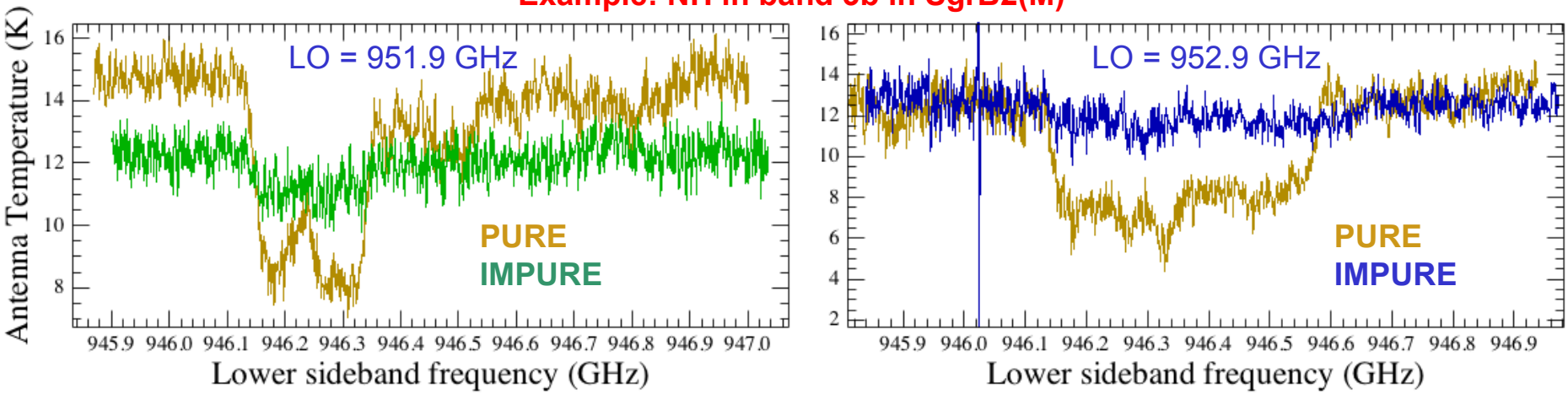
Way forward in post ops: correct observations with impure settings

- There exist a limited number of frequency areas where HIFI is sensitive to signal outside of the sole **LSB** and **USB** ranges
- This results in leak lines and an improper side-band calibration due to the contribution of the leaking range – we call this ***Impurity***
- In SBR term, this translates into a flux loss (in both **USB** and **LSB** calibration), that can be estimated if a purified detector is used
- We have estimated this correction factor for the following areas:
  - Band 5a between 1231 and 1236 GHz (loss between 5 and 50%)
  - Band 3b between 951 and 953 GHz (loss up to 90%)

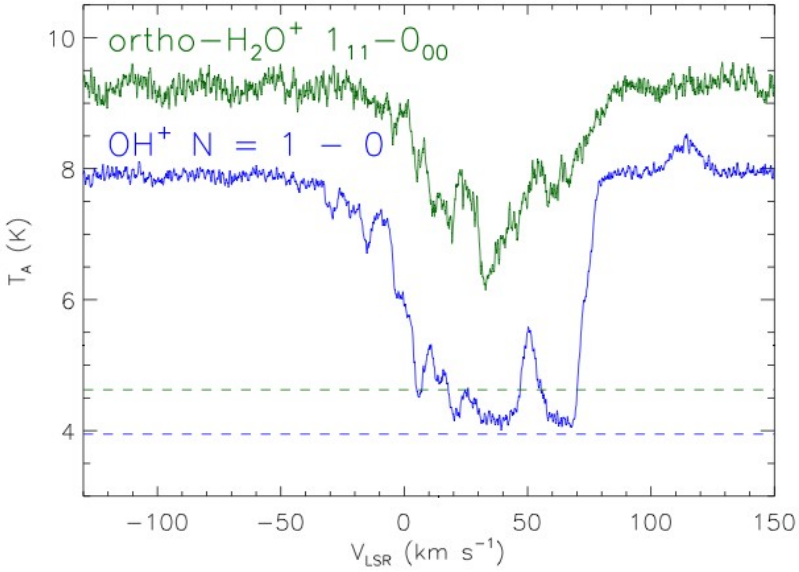
Example: NH in band 3b in SgrB2(M)



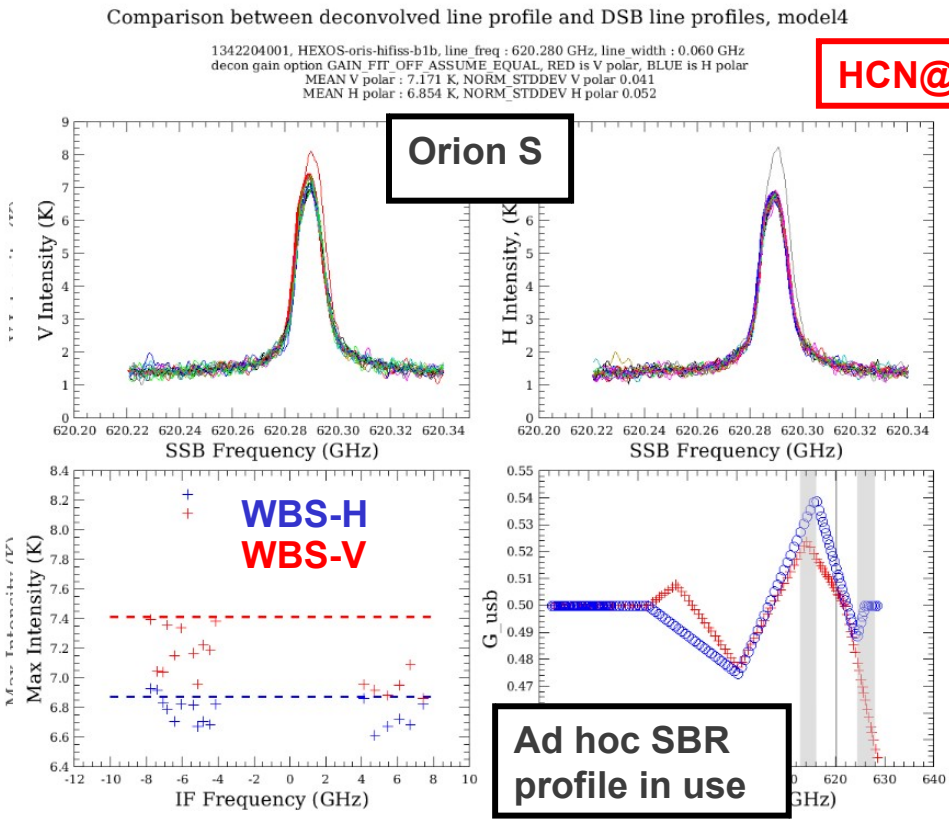
Way forward in post ops: line absorption observations

- Currently when side band ratio is applied it is equally applied to continuum and line intensity. Since continuum is observed in both LSB and USB the side band ratio has no effect on the final value (assuming that continuum doesn't change significantly over 16GHz), and so applying the side band ratio will distort continuum value

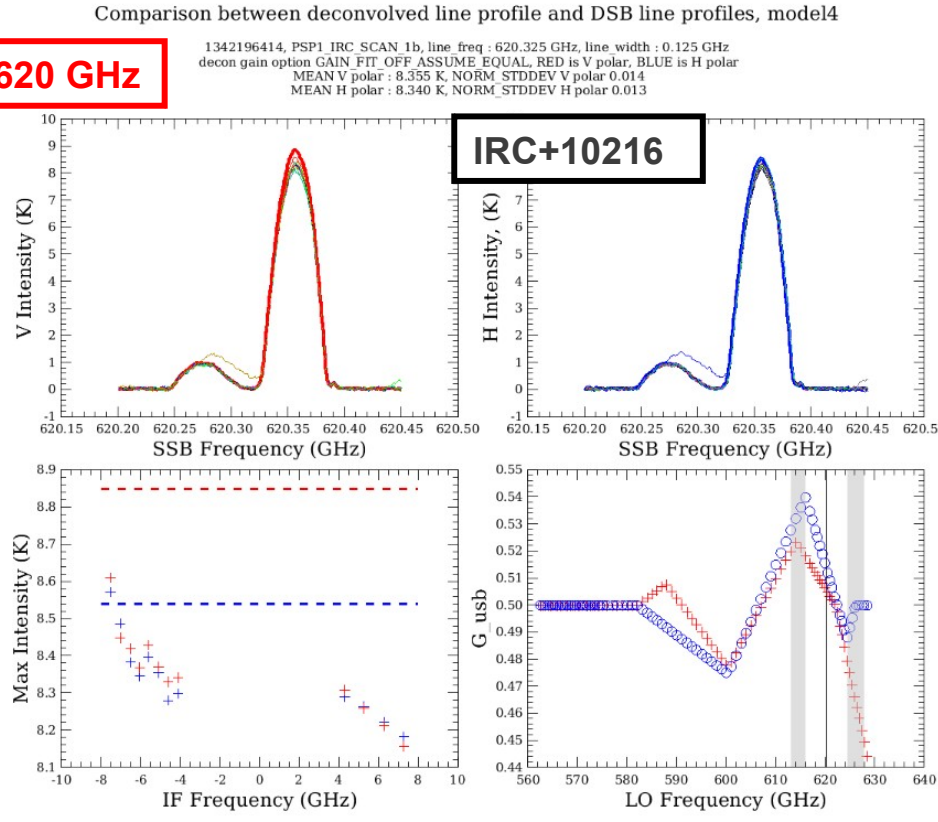
- PRIMAS team developed an approach of undoing the side band ratio correction on the continuum, this approach is described in the up-coming side band ratio technical note



Way forward in post ops: fill in gaps in side band ratio coverage with flight data



HCN@620 GHz



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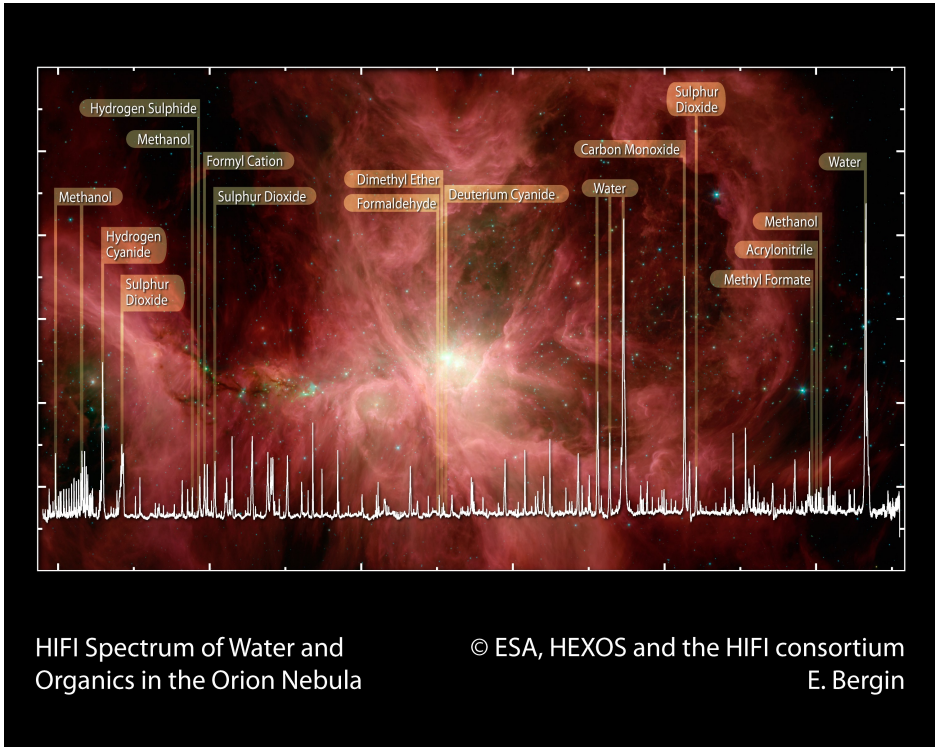
Way forward in post ops: fill in gaps in side band ratio coverage with an optimized deconvolution algorithm



HIFI Spectrum of Water and Organics in the Orion Nebula

© ESA, HEXOS and the HIFI consortium
E. Bergin

- The broadband spectra of HIFI are generated through multiple LO tuning, the board band spectra is then generated using a deconvolution algorithm
- An optimized deconvolution algorithm developed by Do Kester using a Bayesian statistics approach is being used to used to reconstruct the side band ratios
- This shows some encouraging results
- Deconvolution algorithm in its current form produces excellent results (see press release) but is not suitable for side band ration extraction.

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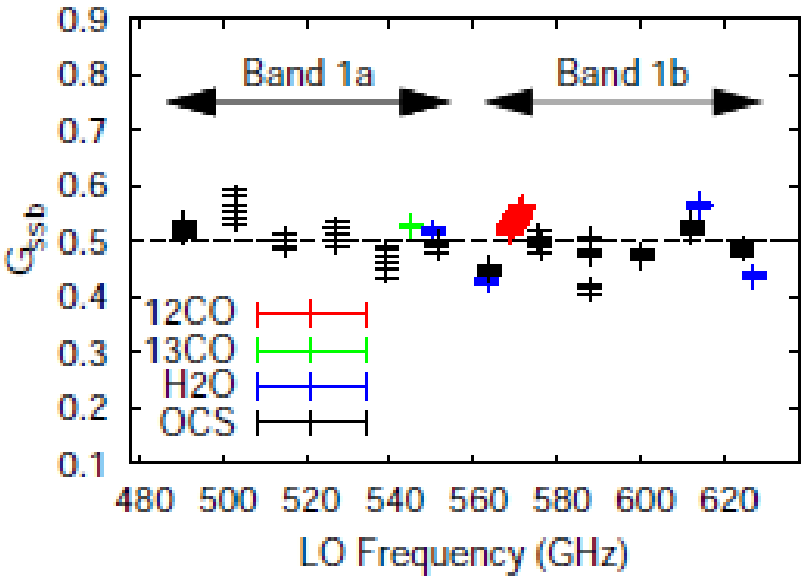
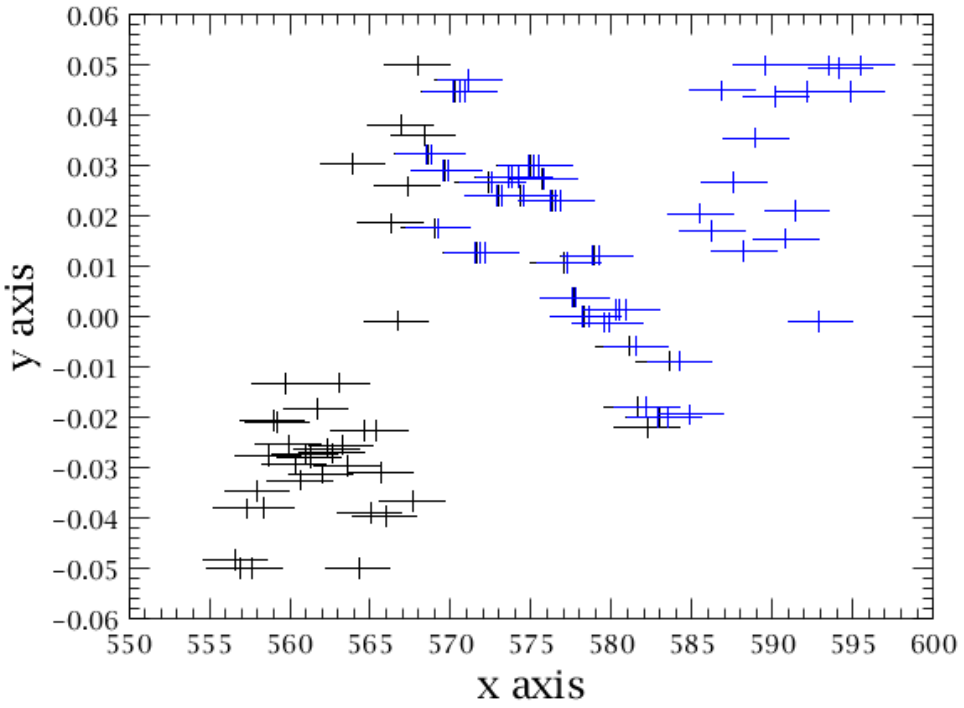
Way forward in post ops: fill in gaps in side band ratio coverage with an optimized deconvolution algorithm



Original gas cell extracted gain



Bayesian statistics approach

Immediate plans

- Release of side band ratio tech note, describing current state of side band ratio understanding to the observers.
- Within this table is a list of spot frequencies for important transitions
- Tech note contains a recipe on how to apply side band ratio, using the 557 GHz line as an example

H_2O							
USB	110-101	550.436	6.5	0.518	0.004	0.511	0.003
LSB	110-101	563.436	-6.5	0.428	0.005	0.431	0.005
USB	532-441	614.200	6.5	0.565	0.003	0.549	0.008

Error Overview

Table 7. Relative (percentual) calibration error budget for the HIFI Instrument.

Error source	HIFI mixer band 1 & 2	3 & 4	5	6& 7
Sideband ratio	3-4	4-6	4	5-8
Hot load coupling[1]	<1	<1	<2	<3
Cold load coupling[1]	<1	<1	<2	<3
Hot load temp.	<1	<1	<1	<1
Cold load temp.	<1	<1	<1	<1
Planetary model	<5	<5	<5	<5
Beam efficiency	<5	<5	<10	<5
Pointing[2]	<1	<3	<4	<8
Opt. standing waves	4	4	3	3

Table taken from in-orbit calibration paper, Roelfsema et al 2012

Error goals and talking away problems

Error source	HIFI mixer band 1 & 2	3 & 4	5	6& 7
Sideband ratio	3-4	4-6	4	5-8

Bands 1&2	Bands 3&4	Band 5	Bands 6&7
Gas cell data is excellent quality, coupled to decon algo, complete understanding is within reach	Gas cell data and flight affected by systematic effects, standing waves coupled to diplexer modulate SBR. Modeling needed to understand the extent of these effects, (see next talk by DelForge)	Impurity issue affected gascell data. Currently applied correction fits data well. Full band coverage already in pipeline.	HEB mixers less susceptible to side band ratio variation compared to SIS due to weaker capacitive impedance component, smaller IF bandwidth. No evidence of SBR from flight data. Original limits sets by gas cell scatter, can be ignored now due to non optimum setup in lab
goal error: 2%	**goal error: unknown**	**goal error: 2%**	**goal error: 2%**