EMIR upgrade of 3mm and 2mm bands
Astronomical Commissioning
v1.1

C. Marka, C. Kramer

December 15, 2015

Contents

1 E090 **4**

1.1 General comments . . . 4

1.2 Sidelobes . . . 6

1.3 H/V comparison. Gain-ratios. . . . 11

1.4 Spurious signals . . . 15

1.5 Local oscillator higher harmonics . . . 15

2 E150 **17**

2.1 General comments . . . 17

2.2 Comparison H/V. Gain-ratios. . . . 17

2.3 Spurious signals . . . 19

3 Alignment and Focus differences **21**

3.1 E090/E230 . . . 21

3.2 E090/E150 . . . 21

3.3 E150/E330 . . . 21

4 Beam widths **21**

5 Main beam efficiencies **23**

6 Cold load **24**

7 References **25**

Abstract

End of November 2015, the EMIR mixers for bands 1 and 2, E090 and E150, were replaced by NOEMA-type mixers. In addition, an ortho-mode transducer was installed for band 1, requiring changes to parts of the internal optics of this band. One of the two cold loads was replaced by a larger one. The new band 1 mixers allow for observations down to 73 GHz extending the previously accessible frequency range (81-116GHz). Astronomical commissioning took place in the first week of December, and is presented here. Tuning of the new mixers went well. Image band rejections of E0 and E1 are, in general, as expected from the lab. New effective cold load temperatures are being used. Several issues were identified.

1. Spectra of the H-polarisation of band 1 show sidelobes next to strong lines. Upto 6 sidelobes are seen; they lie at multiples of 21.6 MHz. Their strengths relative to the main line varies between 1/20 and 1/400, varying with local oscillator frequency over the E0 band. Also the strengths of the sidelobe harmonics relative to each other varies a lot.
2. Gain ratios of band 2 are better than -10 dB for the entire frequency range accessible with E150, except for one frequency setup, where the image band rejections in V-polarisation are strongly degraded when using the default tuning. Gain ratios can, however, be improved by optimizing the mixer bias, resulting in rejections in agreement with the rest of the band.
3. The focus offset of E0 relative to E1 and E3 has changed to 0.4 mm.
4. Alignment between E0/E2 has degraded to $4''$. Alignment between E0/E1 is $2''$.
5. Spurious spiky signals, which leak through into the astronomical spectra, were detected near 108.868 GHz and near 138.86 GHz.

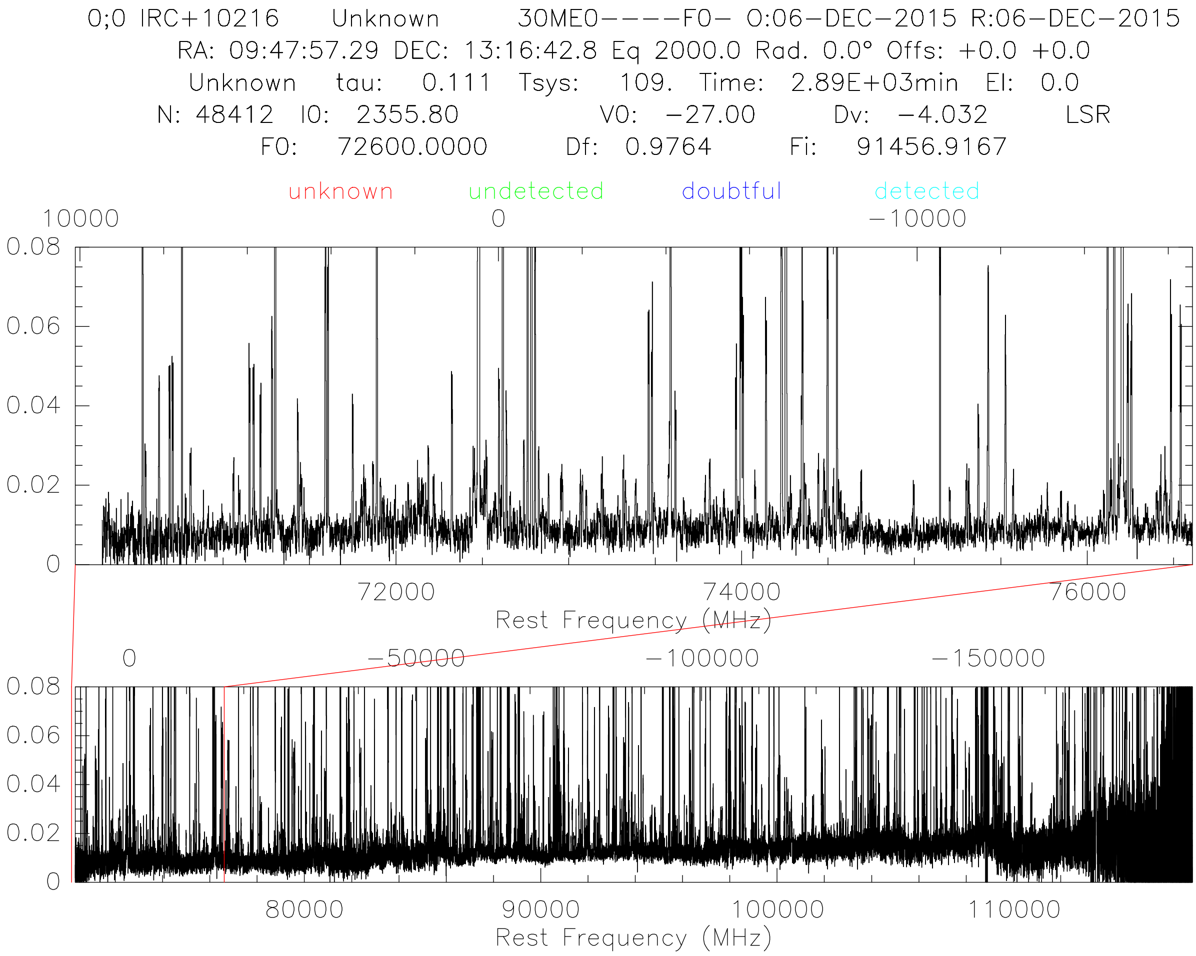

Figure 1: IRC+10216 spectrum covering the entire E090 band from 70.3 to 117.5 GHz.

1 E090

1.1 General comments

Sky frequencies between 72.6 and 115.5 GHz can be tuned. Still lower frequencies are not accessible with the present LO (72.6 corresponds to Flo=82.0). The lower edge observable with the FTS at 200 kHz resolution or with WILMA lies at 70.3 GHz. Tuning is very quick (within about 7 minutes) for almost all frequencies between. Only, at the very low end, tuning took a bit longer.

In general, pointing scans with BBC in Horizontal polarisation are somewhat noisier than those in vertical polarisation.

Figure 2 shows examples of spectra taken with E090 showing a good agreement between polarisations.

However, strong lines observed with E090 exhibit weak sidelobes in the Horizontal polarisation, as discussed below.

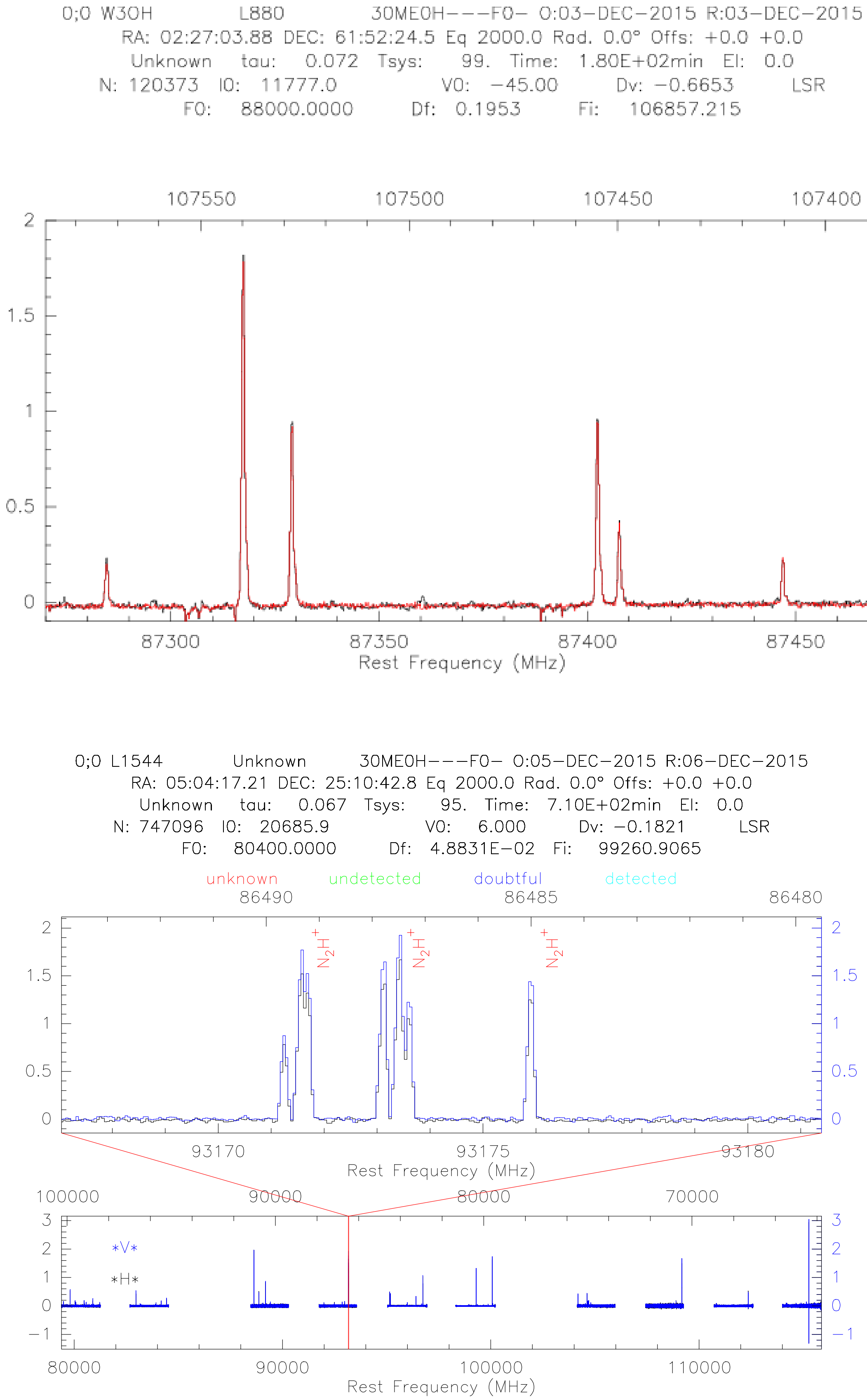

Figure 2: **Upper:** C_2H detected in W3OH. **Lower:** N_2H^+ observed in L1544 (Project 137-15, PI C. Vastel).

1.2 Sidelobes

Sidelobes show-up with E090 in Horizontal polarisation at about $n \times (\pm 21.6 \pm 0.6\,\mathrm{MHz})$ with $n = 1$, 2, 3, independent of tuning, local oscillator frequency and backend. The 3rd harmonics are not always visible. Example spectra are shown in Figures 3 and 4. Sidelobes are reproducible: the same tuning on a different day gives the same result. Their shape resembles that of the main line. They show up on all frequency setups observed (f_{LO}=82.0–105.8 GHz), with strengths ranging from 20 to more than 100 times weaker than the main line (but are roughly consistent for several lines at different frequencies observed in the same setup, see Fig. 4 & 5). For strong lines which show up also in the image band, the sidelobes are also present and damped by much smaller amount than the main line. In the examples shown in Figures 3 and 4, the main line in Vertical is always stronger than in Horizontal.

The strength of the sidelobes relative to the main line varies with local oscillator frequency, as shown in Figure 5. Moving the local oscillator does not alter the position of the sidelobes relative to the main line (Fig. 6).

Observations of very narrow lines in prestellar cores in project 137-15 did show the sidelobes only for one setup (f_{LO}=82.93 GHz, close to the setup where the strongest sidelobes have been seen on IRC+10216) with first sidelobes about 15 times weaker than the main line (Fig. 8).

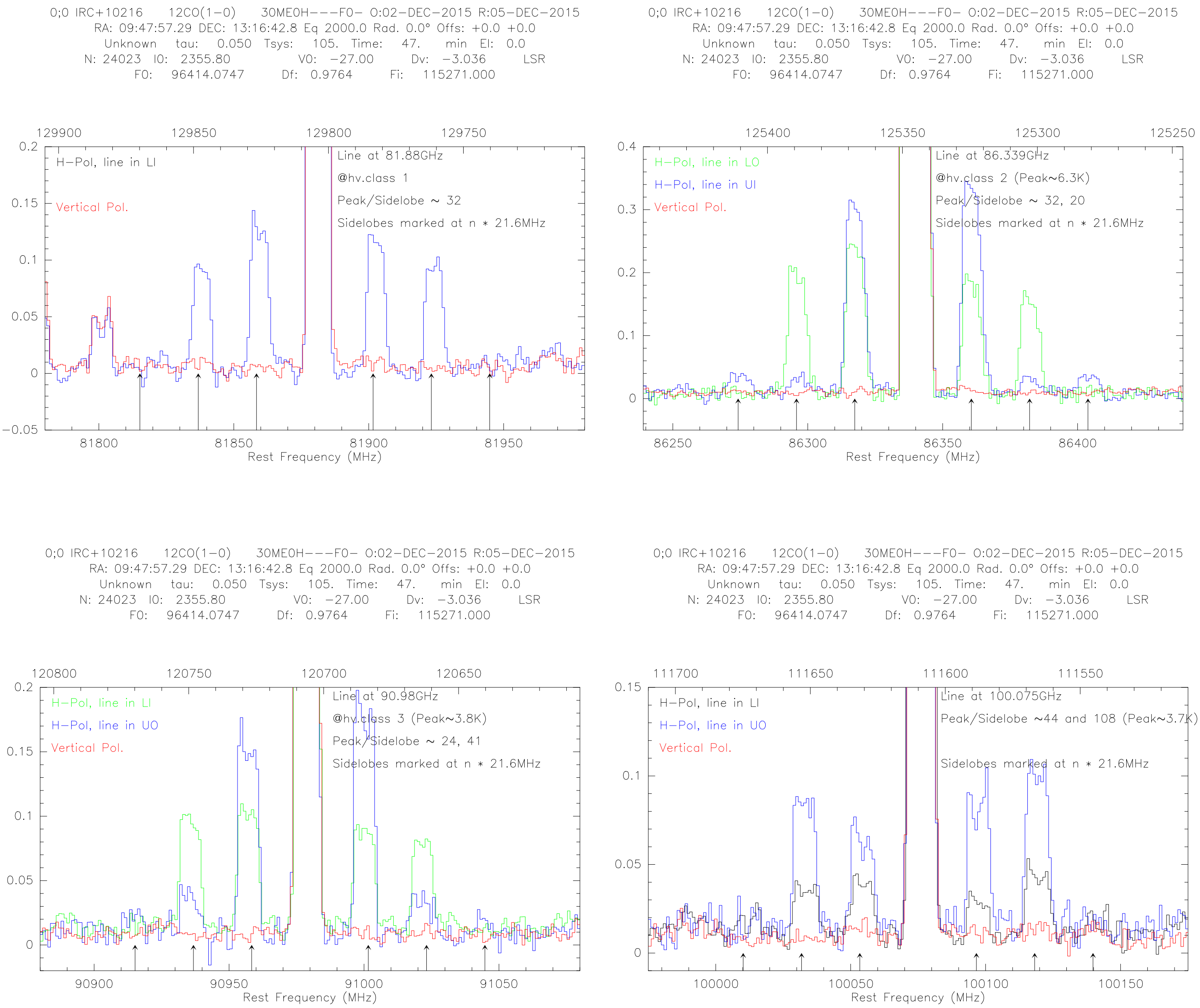

Figure 3: E090 observations show sidelobes in Horizontal polarisation and reduced peak temperatures in H. Up to three harmonics of the sidelobes are visible. They are always spaced by about 21 MHz. Their intensity varies a lot with sideband. In Vertical polarisation there is no evidence for sidelobes.

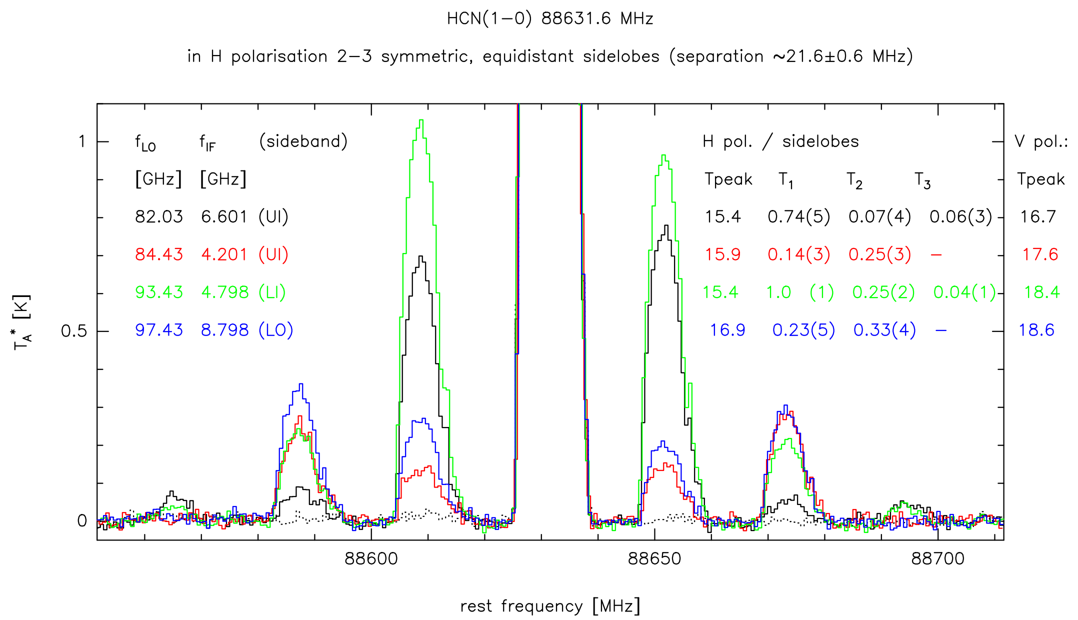

Figure 4: Example of variable sidelobe strengths for a line covered by four different frequency setups. Local oscillator and IF frequencies are indicated on the left, the sidelobe peak and Horizontal/Vertical peak temperatures on the right. Note that peak-to-sidelobe ratios vary between 15 and > 300, and the relative strengths of the 1st to 3rd sidelobe show large differences.

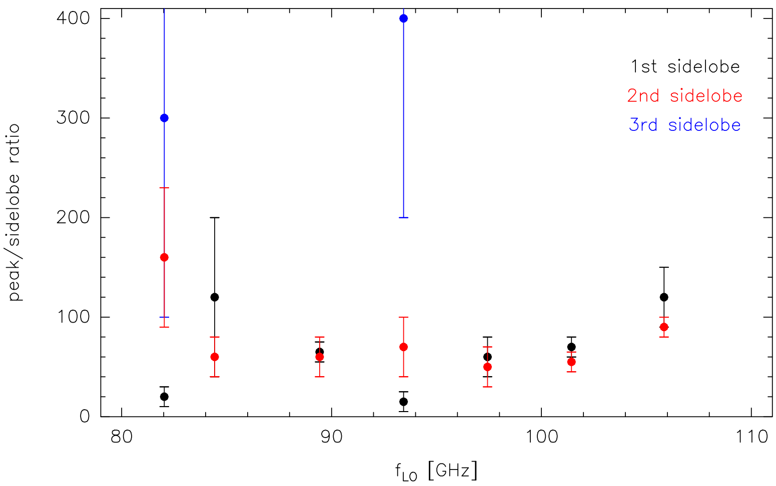

Figure 5: Ratios between main line and sidelobes estimated from $\geq 2\,\mathrm{K}$ lines for several frequency setups.

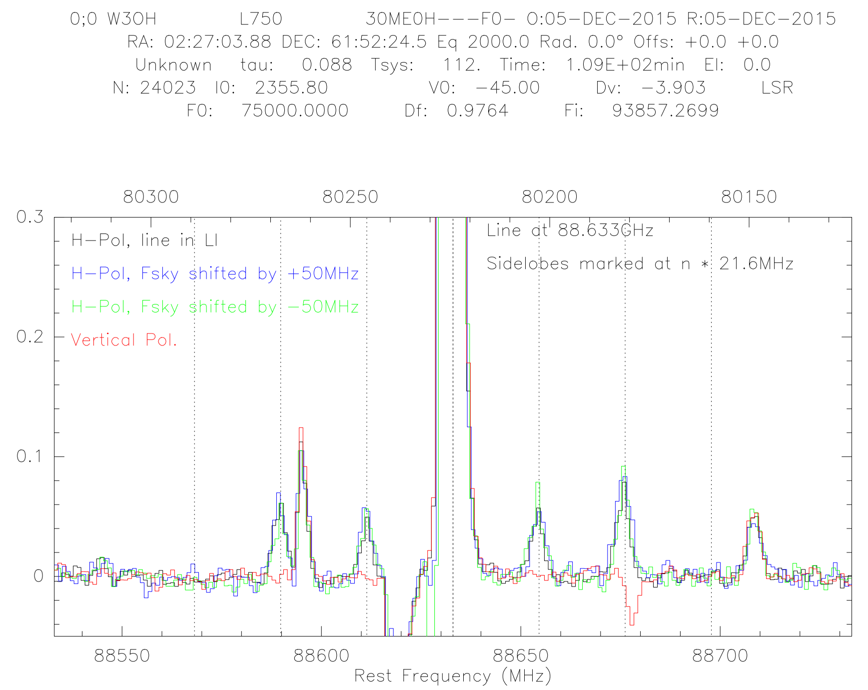

Figure 6: Moving the local oscillator (i.e. the sky frequency) by ±50 MHz does not alter the position of the sidelobes.

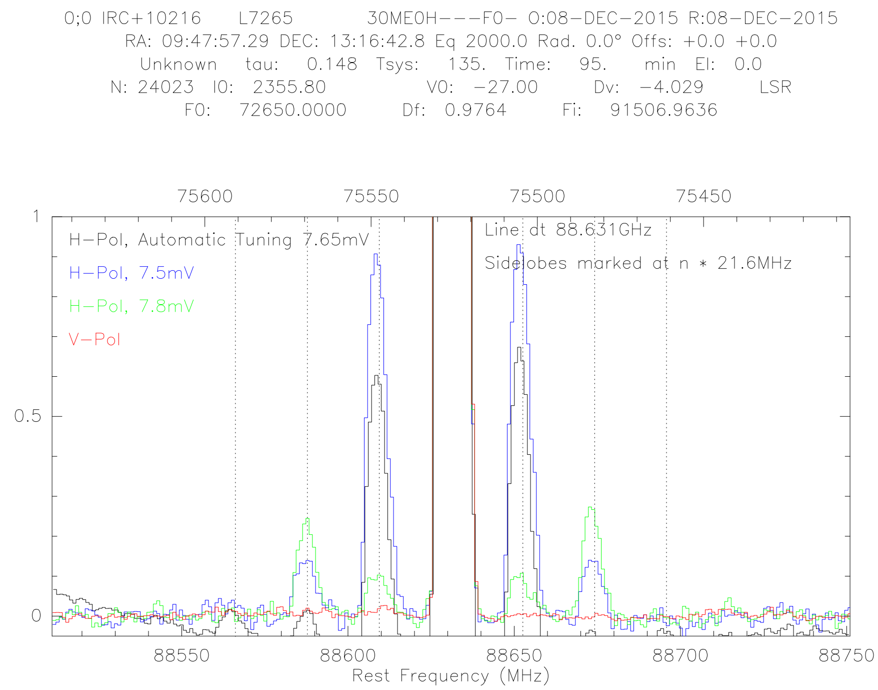

Figure 7: Moving the mixer bias by ±0.05 mV relative to the position of the automatic tuning for both polarisations influences the strengths of the sidelobes.

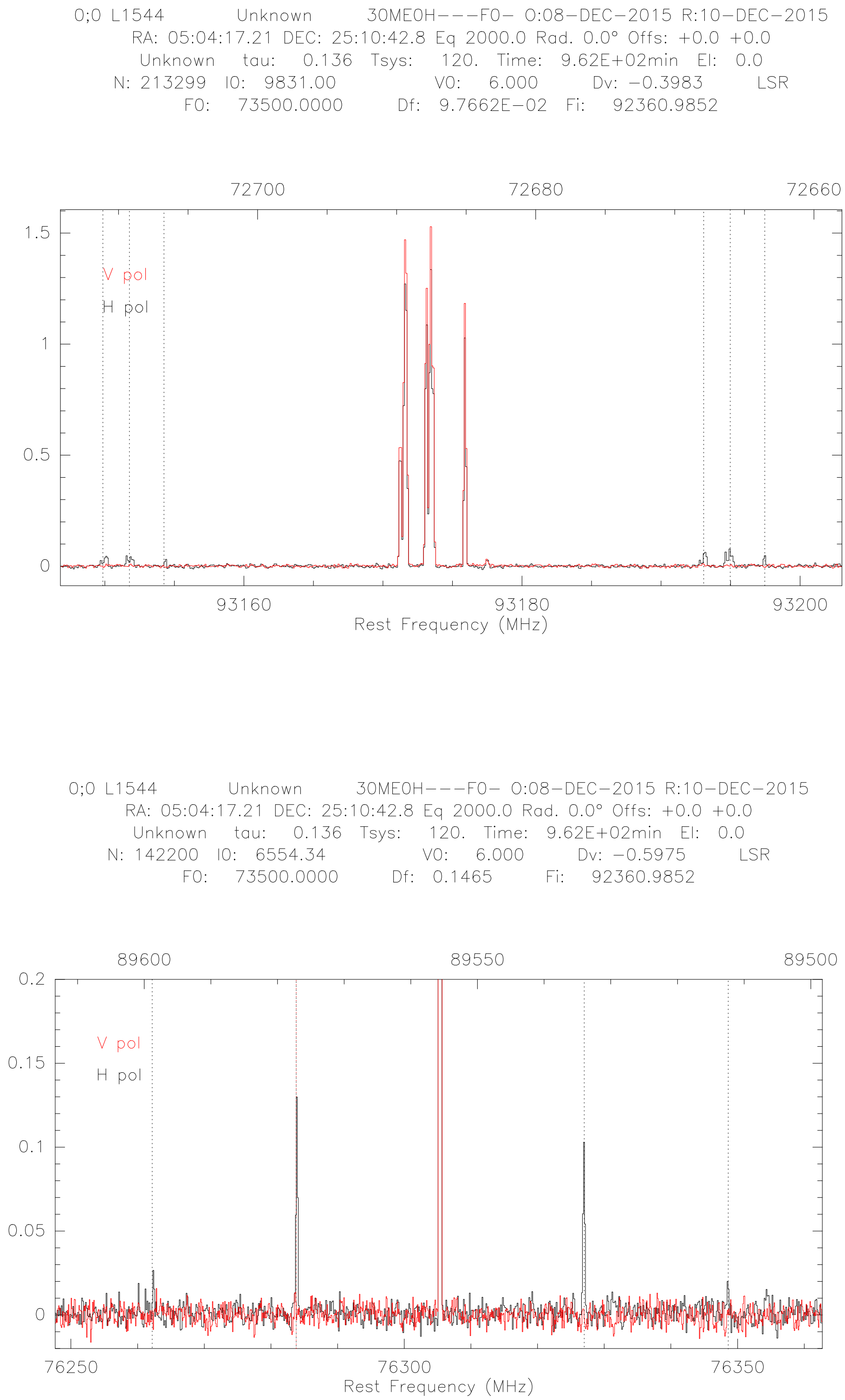

Figure 8: N_2H^+ (upper panel) and DNC (lower panel) lines of FWHM 0.5 kms^{-1} observed in L1544 (Project 137-15, PI C. Vastel) with FTS at 50 kHz resolution, showing sidelobes 15 times weaker than the main lines in H. For DNC(1–0) (peak temperature ca. 1.8 K, baseline rms 5mK), the second sidelobes are just discernable at ca. 1/70 strength.

1.3 H/V comparison. Gain-ratios.

A comparison with literature values for selected lines is given in Table 1. For the majority of lines values agree within 15%, the reason for the large deviation in CS(2–1) is unclear (several transitions as e.g. of CCH and HNC are known to be variable in time [Cernicharo et al. (2014)], but low-J transitions of CS, SiO and SiS are expected to be constant). Applying the lower main beam efficiencies from section 5 reduces the differences to 5% (except CS), but is speculative.

Table 1: Comparison of selected line strengths (H and V averaged) with values from [1] Kahane et al. (1988), where $T_A^* \approx 0.6\,T_{mb}$, and [2] Cernicharo et al. (2014). $F_{\rm eff}$=95%, $B_{\rm eff}$=81-0.1×(f[GHz]-86) – interpolated for E090 range, cf. WiKi on Iram30mEfficiencies – has been applied for the current observations.

Frequency [MHz]	Line	T_A^* [K] literature	ref	T_A^* [K] measured	T_{mb}^{meas} / T_{mb}^{lit}
86846	SiO(2–1)	1.6±0.1	[1]	2.0±0.2	0.88
88632	HCN(1–0)	13.4±0.6	[1]	16.9±1.2	0.88
90663	HNC(1–0)	1.0	[2]	0.9±0.1	0.9
90771	SiS(5–4)	2.5±0.1	[1]	3.3±0.3	0.94
90978	HCCCN(10–9)	3.5±0.5	[1]	4.3±0.2	0.86
97980	CS(2–1)	6.8±0.3	[1]	6.5±0.4	0.68

In general, Horizontal and Vertical polarisation compare well (see e.g. Fig 2). For a subset of stronger lines observed in several frequency setups, the line strength in Horizontal polarisation is 94±11% that of the Vertical polarisation on average. The ratio appears to deviate more strongly at IF frequencies >11.5 GHz (Fig. 9), where also the mixer noise temperatures and image band rejections measured in the laboratory (Fig. 12) degrade, while there is no obvious dependence on line strength, sky or LO frequency.

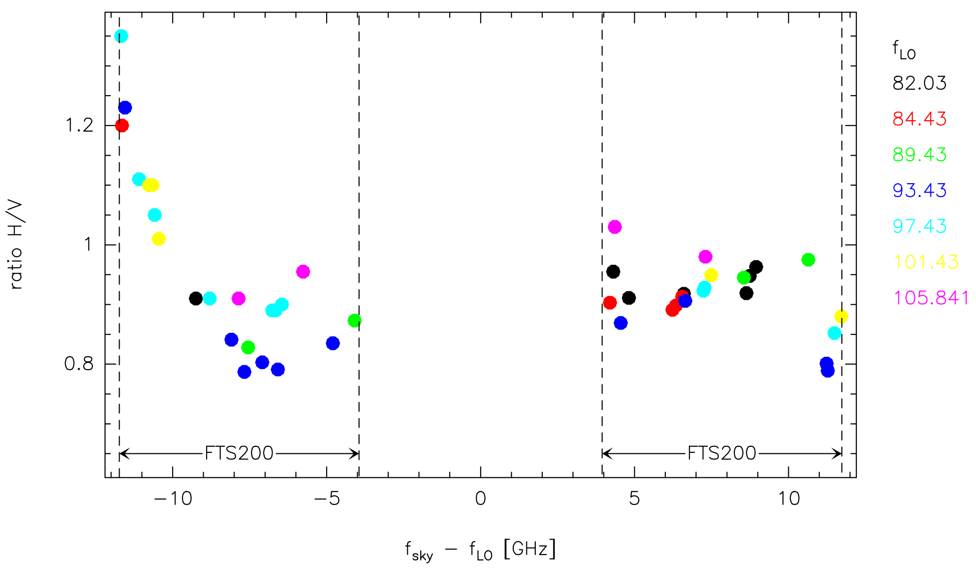

Figure 9: Ratio between Horizontal and Vertical polarisation of several lines versus distance of the lines from f_{LO}. Note the strongly increasing deviation close to the outer edge of the LSB (on the left). Different tunings are denoted by colour.

Gain-ratios of E090 measured over the entire frequency range are shown in Figure 10. Gain ratios are better than −10 dB for the majority of the frequency range in both polarisations. Values of > −10 dB stem from lines close to the outer edge of the covered frequency band, 30–120 MHz from the edge or f_{IF} >11.61 GHz (Fig. 11), which compares well to an increase of image band rejections at high IF frequencies measured in the laboratory (Fig. 12, but see notes in the according caption).

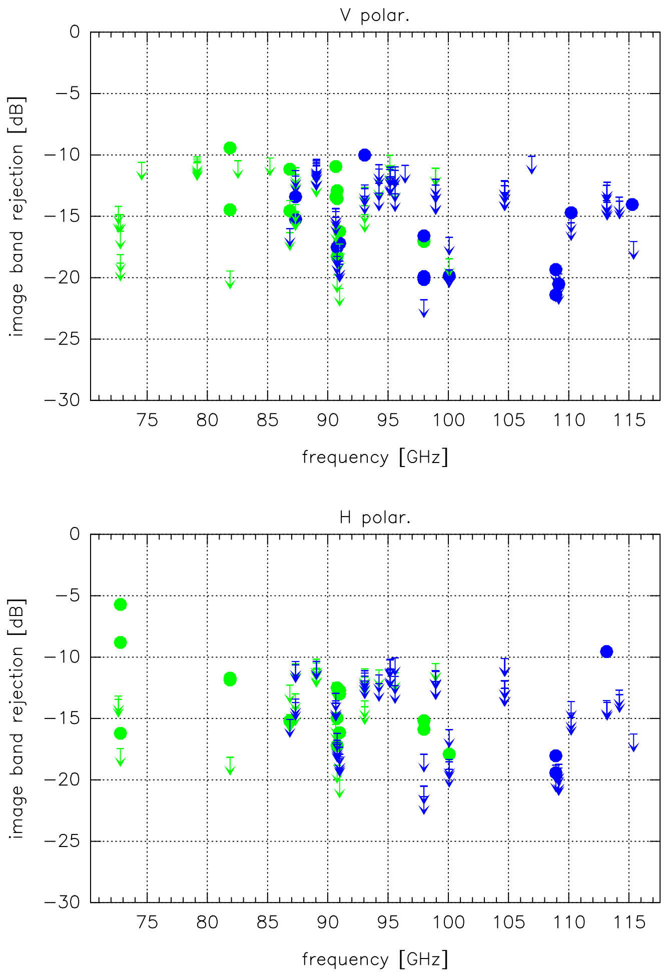

Figure 10: Overview of image band rejections derived from tunings with f_{LO}=82.03, 84.43, 89.43, 93.43, 97.43, 101.43 and 105.841 GHz. Note that the H polarisation may include values affected by the strong sidelobes discussed in the previous section.

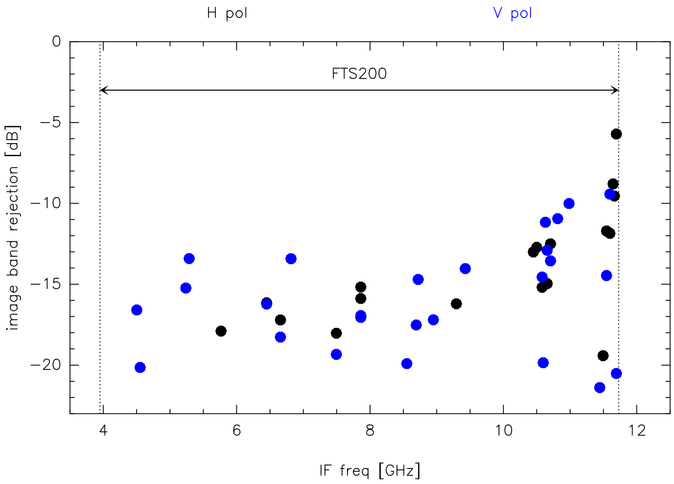

Figure 11: Image band rejections versus IF frequency. The increase at $f_{IF} > 11.6\,\mathrm{GHz}$ is consistent with laboratory measurements.

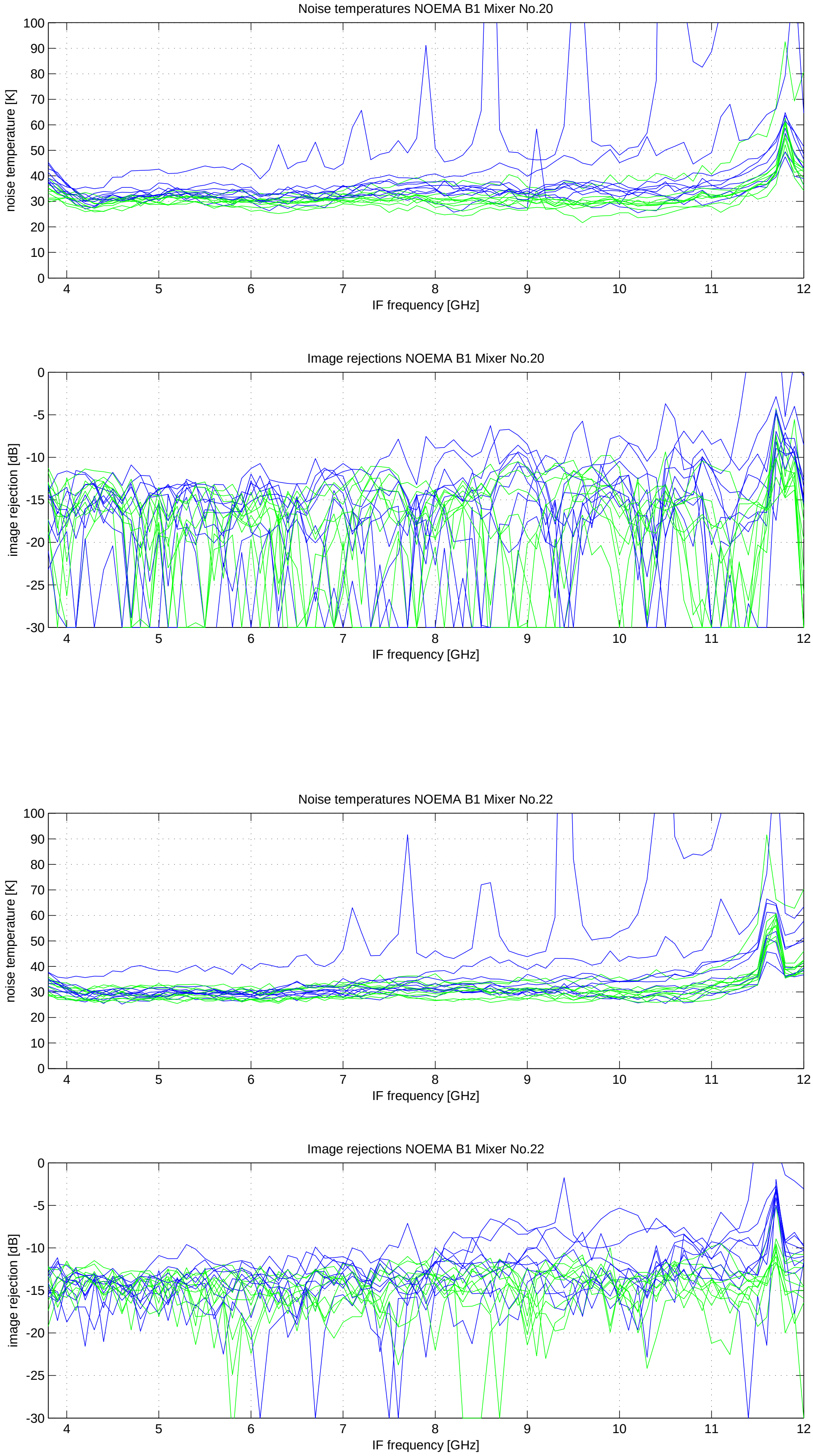

Figure 12: Performances of the new E090 mixers 1&2 as function of IF frequency (periodicities in the image rejections depend on reflections in the RF path as well as in the IF path of the receiver, so might change when installing the mixers in EMIR.) [from D. Maier]

1.4 Spurious signals

On two instances (tunings with f_{LO}=97.43 and 101.43 GHz), a spurious signal was present on calibration scans (for both tunings at 108.868 GHz in the upper sideband, plus their image at the according frequency in the lower sideband), both in Vertical and Horizontal polarisation. In the Horizontal polarisation the signal is accompanied by sidelobes at ∼20 MHz separation like the sidelobes observed on astronomical lines (see Fig. 13). Spurious signals at the corresponding positions also show up in spectra obtained with these tunings. The spurious signal does not move when shifting the LO frequency by 50 or 100 MHz and is also present when the vertex is closed (in which case the signals at the corresponding position in the image band are much stronger), indicating that the signal is produced internally.

While the spurious signal appeared on Dec 2nd and 3rd in a setup with f_{LO}=97.43 GHz, as well as on Dec 4th in a setup with 101.43 GHz, on Dec 8th it was seen neither in setup f_{LO}=97.43 GH nor 99.43 GHz.

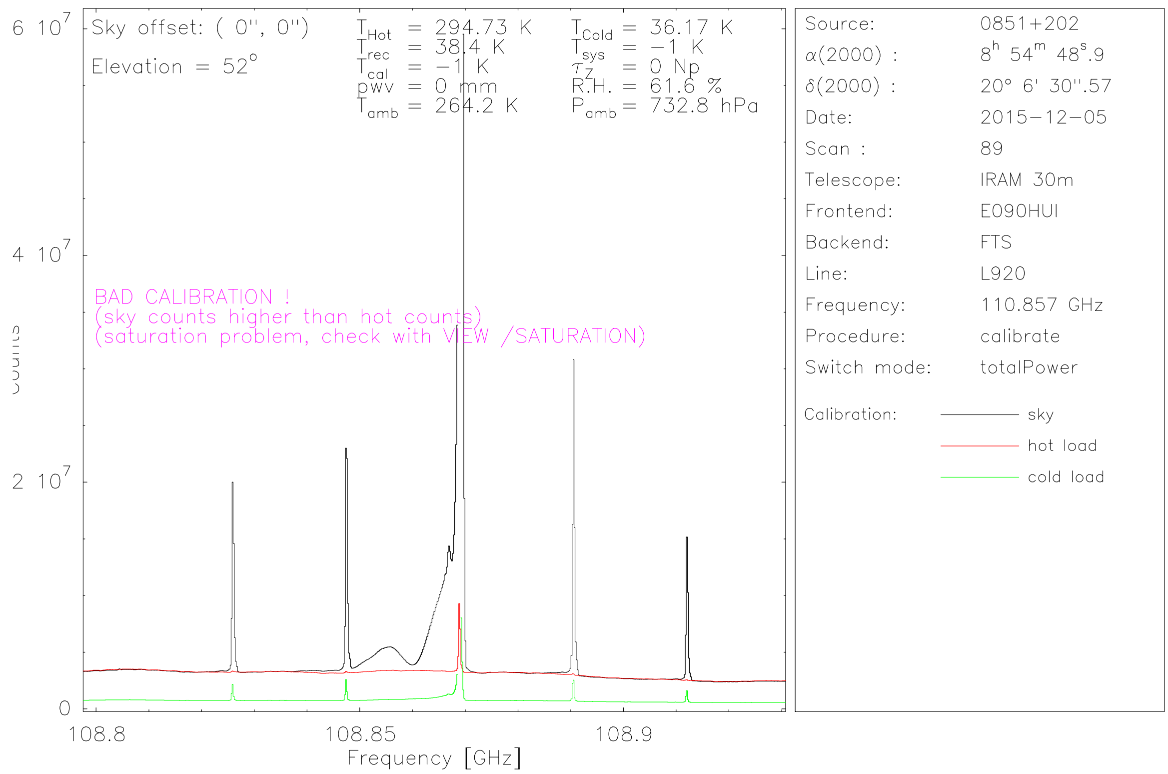

Figure 13: Spurious signal in HUI at 108.868 GHz seen in total power sky/hot/cold spectra. Note that sidelobes are clearly visible (while only the central feature is present in Vertical polarisation). Moving the local oscillator does not change its frequency, indicating that the spurious enters in the RF. Closing the Vertex does not have an effect on its intensity, indicating that it is created internally.

1.5 Local oscillator higher harmonics

For a tuning at the lowest frequency edge (f_{LO}=82.03 GHz), the ^{12}CO(1–0) line at 115.271 GHz in IRC+10216 is mixed with the third harmonic of the fundamental Gunn local oscillator frequency (for E090 there is no multiplier, i.e. the local oscillator frequency is given by the 2nd harmonic of the fundamental frequency of the Gunn oscillator, 41.015 GHz in this tuning, with the 3rd harmonic at 123.045 GHz), creating a ghost line at 74.265 GHz as noted by J. Cernicharo (Fig. 14). The origin of the ghost line is evident from having a linewidth (in MHz) similar to that of the original line and hence a factor of 1.5 broader than lines adjacent to the ghost, and from moving by 25 MHz when the local oscillator frequency is shifted by 50 MHz due to only partial correction of this shift (cf. report on EMIR ghost lines, Kramer et al. August 2014). Ghosts (about a factor of 35 weaker than the original line) are also seen for other sufficiently strong lines from the LSB of the higher-order harmonic (e.g. CN, 3 K at 113.49 GHz seen as ghost at 72.48 GHz, CH_4, 1 K at 114.2 GHz seen as ghost at 73.18 GHz).

No mixing with the 3rd harmonic is noted in the next higher frequency setups (f_{LO}=82.53 & 84.03 GHz).

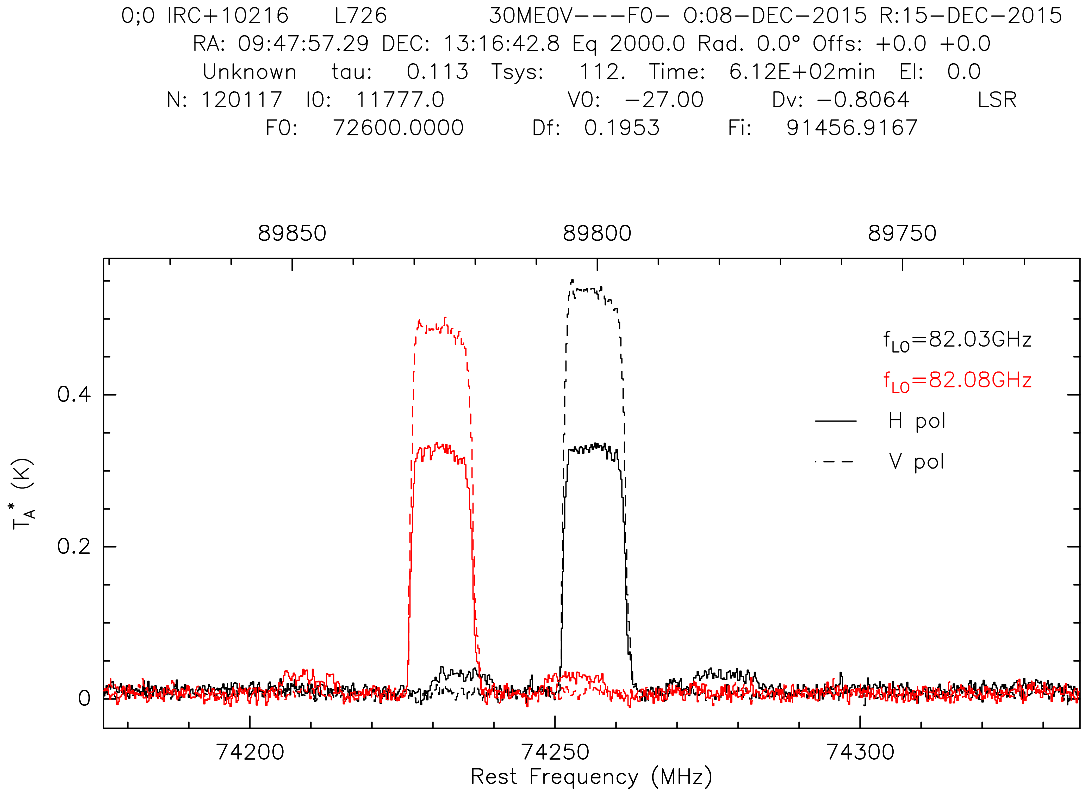

Figure 14: Ghost of the ^{12}CO(1–0) line at 74.2 GHz in IRC+10216, created by mixing with the 3rd harmonic of the fundamental Gunn oscillator frequency. The ghost moves by 25 MHz for two local oscillator frequencies shifted by 50 MHz, and has a width of ∼44 km/s, compared to ∼29 km/s for correct lines in this source.

2 E150

2.1 General comments

Frequencies between 124.6[1] and 183.4 GHz can be tuned. Tuning works smoothly in general, and only takes longer at the lowest frequency (124.6 GHz).

Pointing scans with BBC are somewhat noisier in Horizontal than in Vertical polarisation.

2.2 Comparison H/V. Gain-ratios.

Comparison of spectra obtained on IRC+10216 with previous observations (2013 and 2014) and literature values shows somewhat lower line strengths in the current observations (Tab. 2, Fig. 15). However, note that line strengths in 2014 observations are even lower, so that no firm conclusions can be drawn.

Table 2: Comparison of selected line strengths (H+V and frequency setups averaged, but setup with poor gain ratios omitted) with values from Cernicharo et al. (2000), observations during October 2013 (after E150 upgrade) and 2014 (obtained in project 013-14, where setup with poor gain ratios have been omitted). $F_{\rm eff}$=93%, $B_{\rm eff}$=73-0.16×(f[GHz]-145) – interpolated for E150 range, cf. WiKi on Iram30mEfficiencies – has been applied for 2013–2015 observations. [1] Up to ca. ±20% variation between different frequency setups and polarisations; for data from 2013 and 2014 the variation has not been checked.

Frequency	Line	literature	2013	2014	2015 [1]
		$\int T_{mb}$ dv	$\int T_{mb}$ dv	$\int T_{mb}$ dv	$\int T_{mb}$ dv
[MHz]		[K km/s]	[K km/s]	[K km/s]	[K km/s]
136464	HCCCN(15-14)	132±23	132	85	106
137180	SiC_2(6–5)	76±35	70	53	63
145227	SiS(8-7)	329±70	341	–	276
146969	CS(3–2)	337±89	525	–	358
154656	HCCCN(17–16)	75±24	121	73	86
163376	SiS(9–8)	283±53	518	–	353

For all except one tuning, line intensities in Horizontal and Vertical polarisation agree very well (H/V=102±10% on average) and only show a larger deviation at high IF frequencies (Fig. 16).

Image band rejections derived from strong lines are in the range **−12 to −17 dB** for both polarisations (see Fig. 18).

Surprisingly, one tuning (131.081 LI, corresponding to f_{LO}=137.331 GHz), which showed degraded gain ratios already with the previous mixers used before the upgrade (cf. report by Marka et al. of March 2015), showed again very poor gain ratios in Vertical polarisation. Using the automatic tuning procedure results in an unsuspicious calibration except for an increased Trec=60-70K in V. Spectra however show line strengths in Vertical polarisation a factor of 2–3 weaker than in Horizontal, and image lines in Vertical polarisation are up to twice as strong as the signal lines (see Figure 17). The mixer bias in automatic tuning (7.67mV) appears only slightly off the optimum point. Adjustment by the operator to 7.55mV (close to optimum, with spikes on calibration) or only 7.6mV, requiring adjustment of FTS levels, reduces receiver temperatures to 40–50K for Vertical polarisation and results

[1]With version pakoTest, frequencies below 125 GHz still require "set emircheck relaxed".

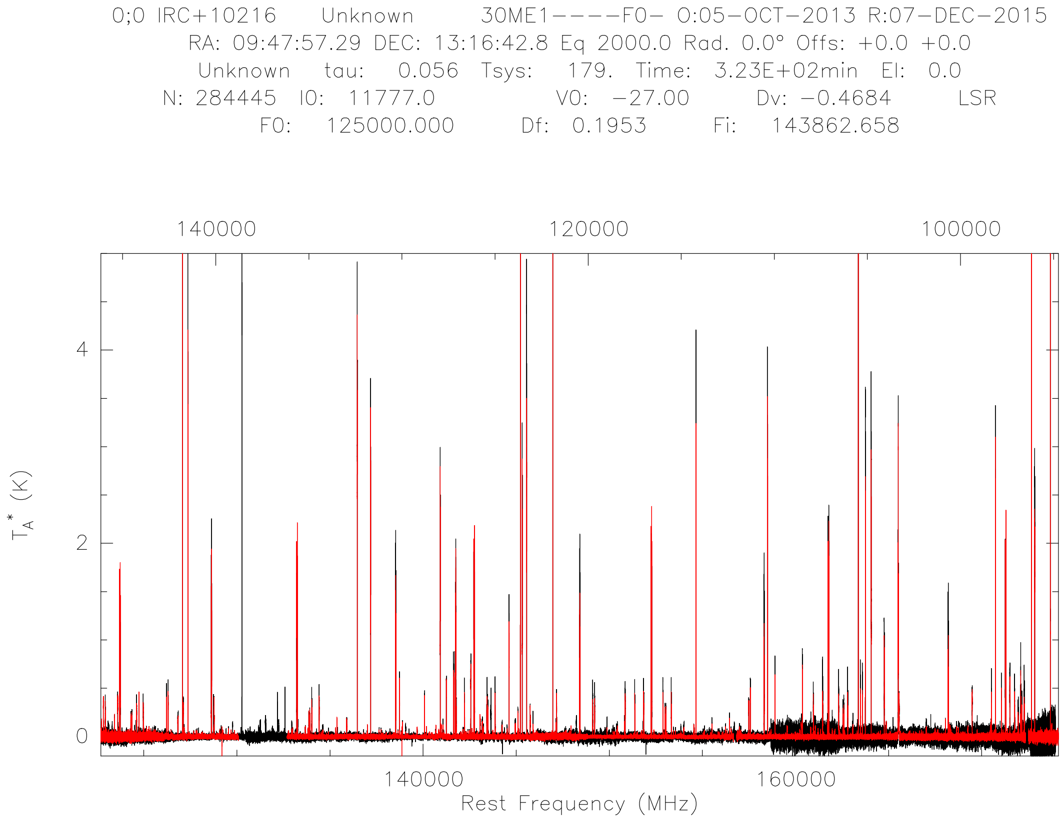

Figure 15: Spectra of IRC+10216 from October 2013 (black) and December 2015 (red).

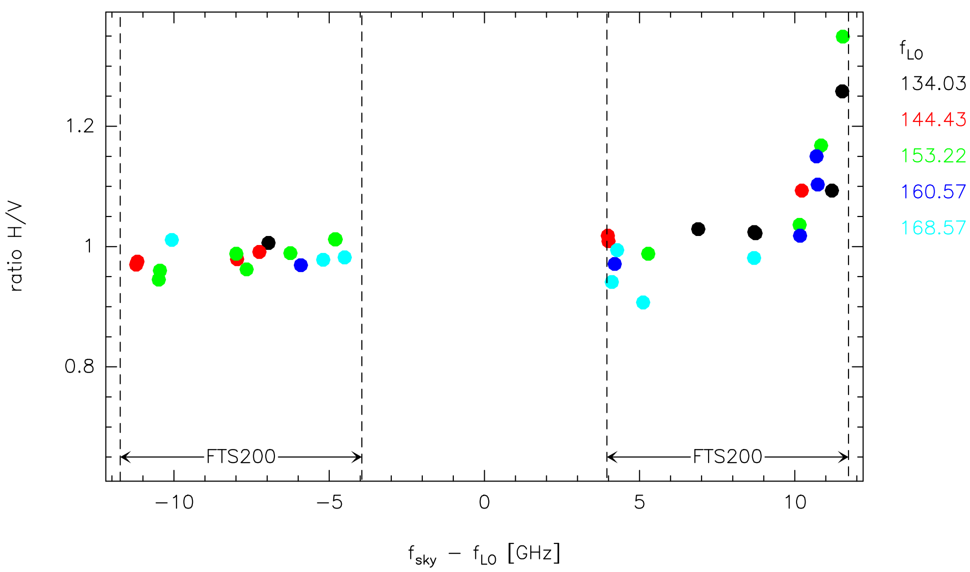

Figure 16: Ratio between Horizontal and Vertical polarisation of several lines versus distance of the lines from f_{LO}. The ratio deviates significantly from unity towards the outer edge of the USB. Different tunings are denoted by colour and their LO frequency.

in spectra with much improved H/V agreement and image band rejections (Fig. 17 & 18).
The problem is not obvious on calibration, but notable for observers on line calibrators or spectra on a strong source; manual adjustment of tuning parameters seems to help at least for this frequency.

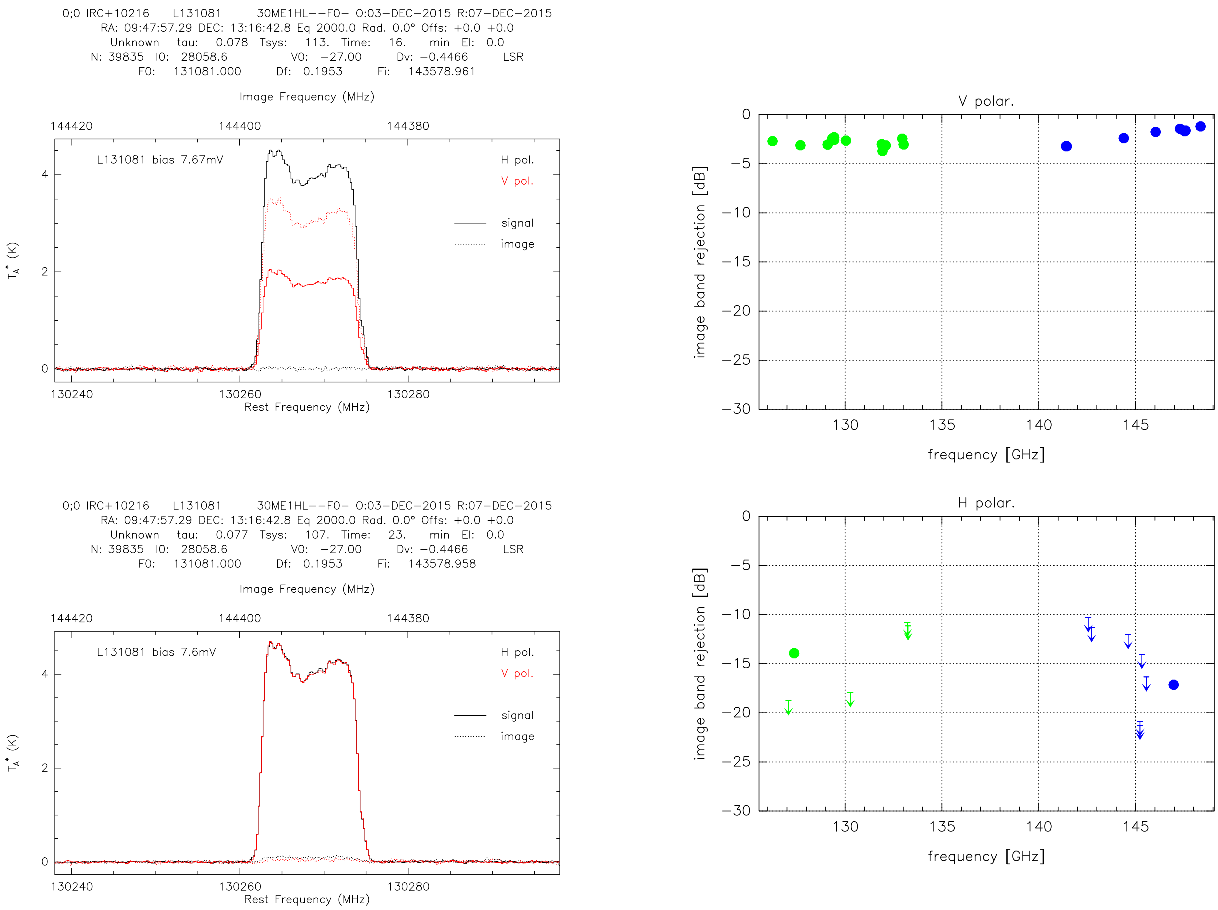

Figure 17: **Left upper panel:** poor agreement between Vertical and Horizontal polarisation on SiO line in IRC+10216 in automatic tuning. **Left lower panel:** The agreement is well after a small adjustment of mixer bias. The peak temperature in Horizontal polarisation agrees with literature values within 30% (Cernicharo et al. 2000). Solid and dotted lines denote the signal and image, respectively. **Right upper panel:** Very poor image band rejection in Vertical polarisation for the automatic tuning of 131.081 LI. *The scale in Vertical polarisation has the wrong sign, since in fact the image lines are stronger than the signal lines.*
Right lower panel: Gain ratios after adjustment of mixer bias.

2.3 Spurious signals

Only one spurious signal was seen in a tuning with f_{LO}=134.03 GHz in the Vertical polarisation at 138.86 GHz (and the corresponding frequency in the image band), coinciding with a spurious signal on the calibration scan (Fig. 19). The spurious signal is not present in a different tuning containing the same frequency.

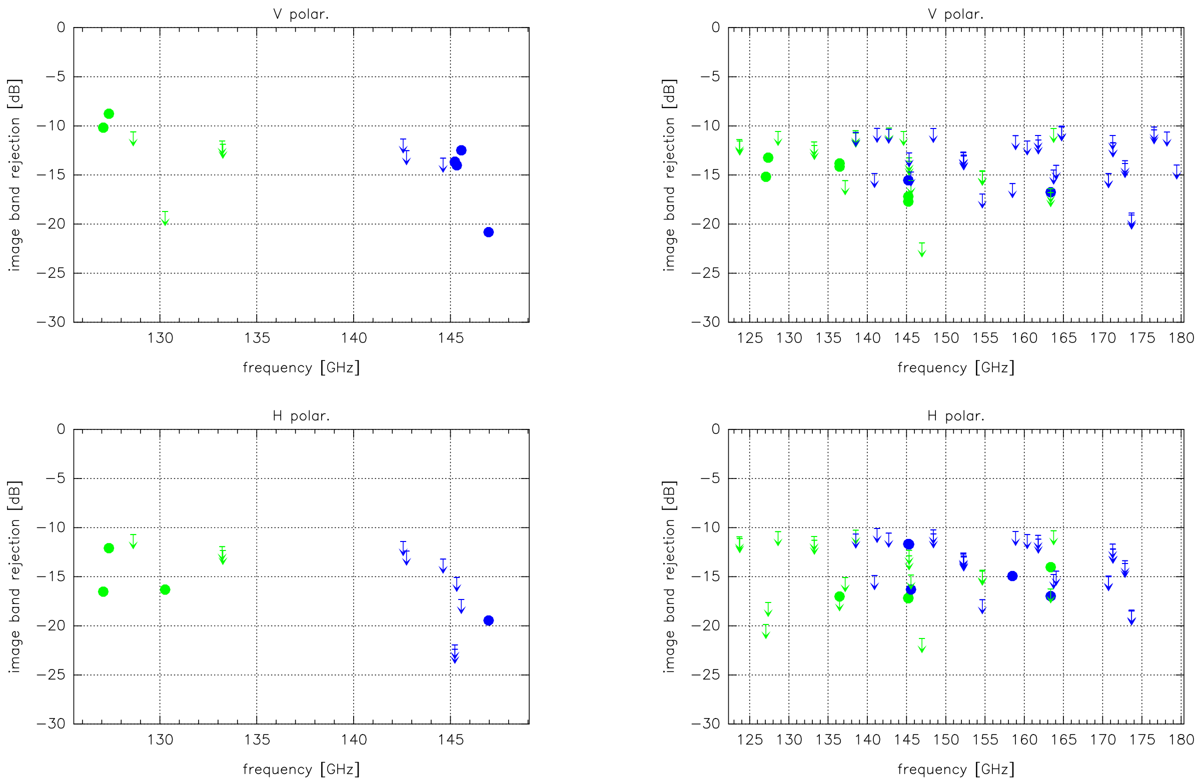

Figure 18: Left: Image band rejections for tuning 131.081 LI with mixer bias reduced by 0.07mV compared to automatic tuning (note the strong difference in V to Fig. 17. Right: Rejections from five more tunings with local oscillator 134.04, 144.43, 153.219, 160.57 and 160.575 GHz. Values are within the expectations. Rejections were derived from strong (>3rms) lines on IRC+10216; arrows indicate upper limits (only limits < -10dB are shown) where no image line is deteced. Green colour denotes LSB, blue USB.

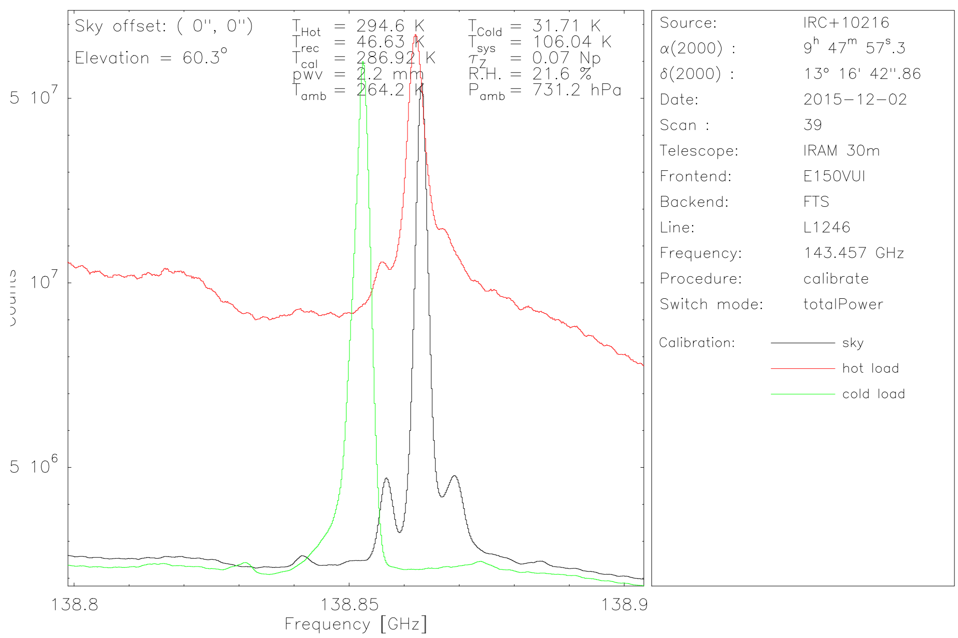

Figure 19: Spurious signal in VUI at 138.86 GHz seen in total power sky/hot/cold spectra, which also shows up as spurious signal in Vertical polarisation in spectra taken with the same tuning.

3 Alignment and Focus differences

The mixers, horns, and part of the internal optics of E090 were changed during the upgrade. We therefore checked for any focus and alignment difference in dual-band observations.

3.1 E090/E230

Observations on Uranus show that there are significant alignment and focus differences between E090 and E230: **3.7″±0.4″ and 0.4 mm±0.1 mm** (E0 has the more positive focus offset) (Table 3). Before the upgrade of EMIR, the alignment was better, $\sim 1''$ (cf. WiKi on TelescopeSystemStatus). The focus offset was 0.14 ± 0.1 mm (from two good scans taken during flux monitoring by H. Ungerechts et al.).

3.2 E090/E150

The pointing offset between E0 and E1 is **2.2±0.5″**, while the focus offset is **0.40±0.1 mm**. E0 has the more positive focus offset (Table 3). Before the EMIR upgrade, the alignment was 2″ (cf. WiKi on TelescopeSystemStatus) and the focus offset was near perfect, 0±0.1 mm (from two good scans taken during flux monitoring by H. Ungerechts et al.).

Table 3: Relative alignment between EMIR bands and focus differences. E1/E3 shows perfect alignment within the errors of about 0.5″ and 0.1 mm.

Band	Az [″]	El [″]	z-Focus [mm]	Comments
E0	1.8	2.5	−1.7	2-Dec-2015, Uranus
E2	-1.9	2.0	−2.1	
Diff E0-E2	3.7	0.5	0.4	Alignment = 3.7″
E0	2.9	2.9	−1.65	3-Dec-2015, Uranus
E1	1.6	1.1	−2.05	
Diff E0-E1	1.3	1.8	0.4	Alignment = 2.2″
E1	3.4	1.7	−2.1	3-Dec-2015, Uranus
E3	3.4	1.7	−2.1	
Diff E1-E3	0	0	0	

3.3 E150/E330

For completeness, we also checked E1 in combination with E3. The alignment is near perfect **0±0.5”** and no focus offset was found: **0±0.1 mm**. Before the upgrade, an alignment of 0.3″ had been measured (cf. WiKi on TelescopeSystemStatus).

4 Beam widths

The measured FWHMs on Uranus follow the relation HPBW = C / Frequency with C between 71 and 160 GHZ being constant, within a scatter of only 4%. The average value of 2450 is very near the value found previously of 2400 (Kramer et al., Errorbeam report, August 2013). Beams are Gaussian within the noise. In particular, no deviations from Gaussianity indicative of beam truncation are noticed at

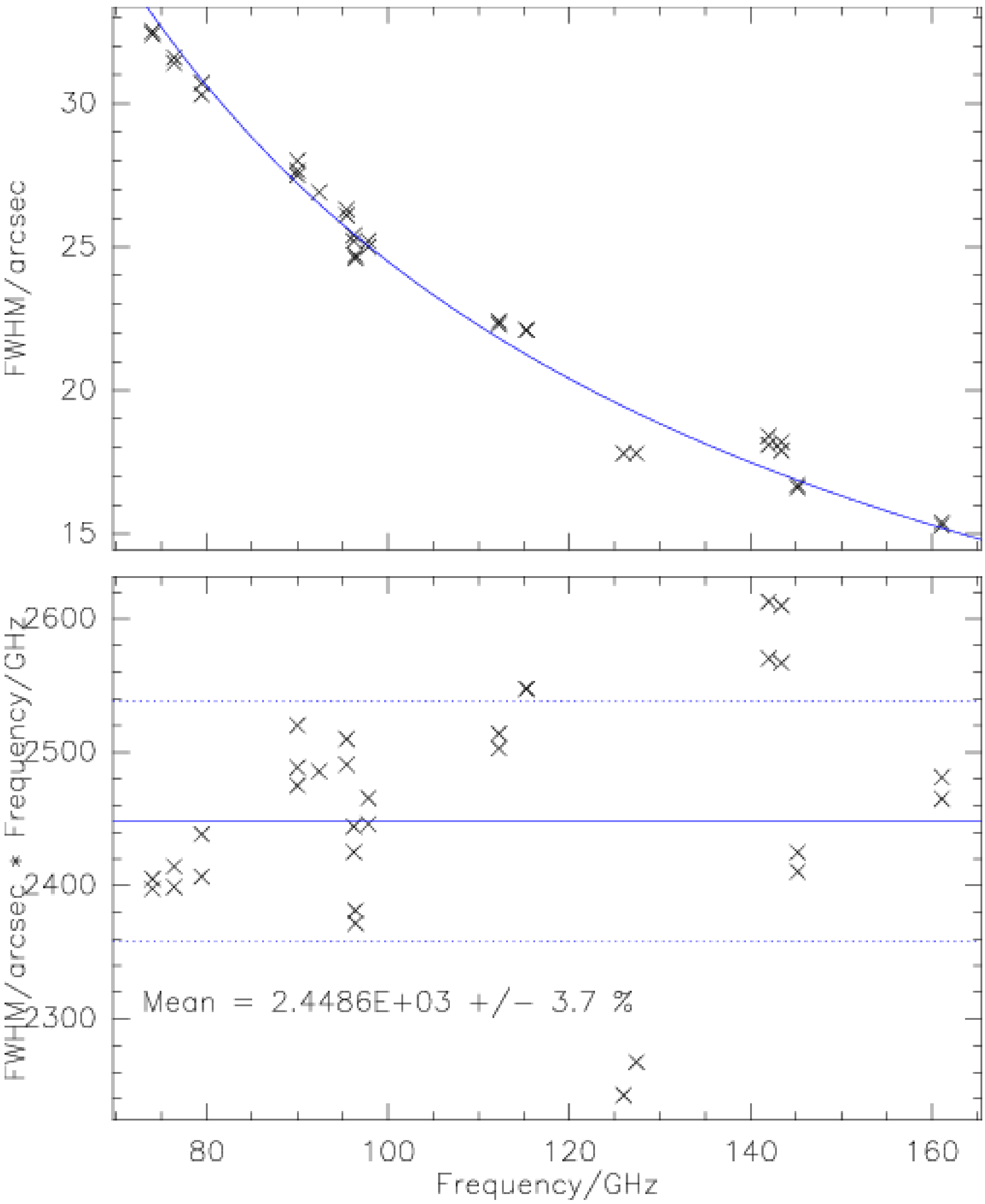

Figure 20: Half power beam widths measured on Uranus (3.6″), separately for H and V, measured with BBC (and partially with NBC).

the low frequency end. No signs of ellipticities comparing H and V are found (differences not shown here).

5 Main beam efficiencies

Mars and Uranus were used to measure main beam efficiencies B_{eff}. In the first week of December, both planets were pointlike. Mars had a diameter of 4.8″ while Uranus had 3.4″.

Main beam efficiencies tend to be a bit low, but are consistent with previously observed values within 10% (Fig. 21, Table 4).

Table 4: Telescope half power beam width and forward, main beam, and aperture efficiencies measured on Uranus with BBC in wobbler switching mode. H and V are averaged.

Frequency GHz]	FWHM [″]	T_A^* [K]	B_{eff} [%]	Planet, Date
74	33.5	0.89	73	Uranus, 3-Dec-2015
74	32.6	0.97	75	Uranus
90	27.8	1.18	72	Uranus
90	27.6	1.21	73	Uranus
145	17.4	2.39	68	Uranus
161	16.3	2.60	67	Uranus
228	10.8		65	Mars
244	10.2		65	Mars

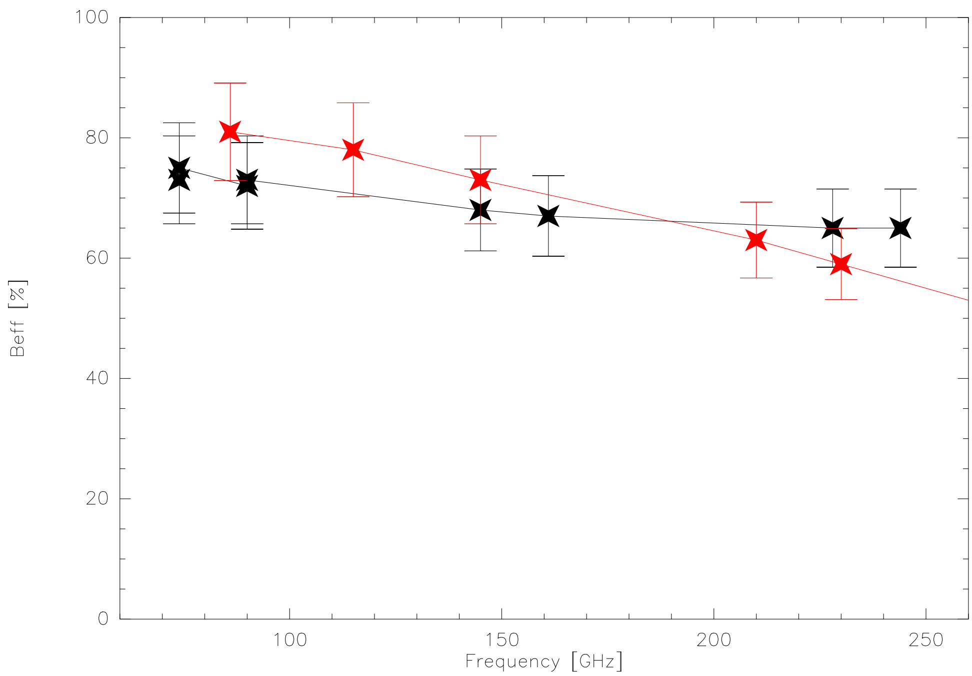

Figure 21: Main beam efficiencies. Efficiencies in black were observed during commissioning. Efficiencies in red are efficiencies measured in the past (cf. 30m WiKi page).

6 Cold load

EMIR uses two cold loads (A, B) depending on which band combinations is being selected. E0 and E2 always use load A. E3 always uses load B. E1 uses load A for the configuration E0/E1, while E1 uses load B for the configurations E1 and E1/E3. See Carter et al. (2012) for more details.

For this EMIR upgrade, the cold load A has been replaced by a new load with improved material properties and somewhat increased size. The receiver group has measured the effective cold load temperatures of the new load A against frequency (polarisation and sideband) for E0, E1, and E2, and also the effective cold load temperatures of load B for the new mixers of E1. Some curves show a variation by ± 5 K. Low-order polynomials have been fitted to the temperature curves, and implemented in the telescope calibration software (Figs. 22).

The correct implementation of the equivalent temperatures for the new cold load A used by the bands/band combinations E0, E2 and E0/E1 (as well as the distinction for E1 to use cold load B when used alone or in combination E1/E3) has been checked for one frequency setting each.

Note that currently and until now, the same cold load temperature is set for both lower and upper sideband, and derived from the frequency set in pako, i.e. not the center of the covered frequency range and not unambigious. This should be acceptable as long as the variation of cold load temperatures e.g. between sidebands is negligible relative to the introduced calibration error of antenna temperatures. CHECK

Figure 22: Effective cold load temperature curves measured after the upgrade of EMIR, together with fitted polynomials which have been implemented in the calibration software.

7 References

- Carter et al., 2012, A&A, 538, 89, "The EMIR multi-band mm-wave receiver for the IRAM 30-m telescope"
- Cernicharo et al., 2000, A&AS, 142, 181
- Cernicharo et al., 2014, ApJ, 796, L21
- Kahane et al., 1988, A&A, 190, 167
- Kramer, Peñalver, Greve, 26-August-2013, "Improvement of the IRAM 30m telescope pattern", V8.2
- Kramer, Navarrini, Navarro, John, Cernicharo, 21-August-2014, "EMIR ghost lines", V1.2
- Marka, Kramer, Navarro, John, 30-March-2015, "Measuring image band rejections on-the-sky. A 2 mm survey of IRC+10216.", V3.0