Measuring image band rejections on-the-sky. A 2 mm survey of IRC+10216.

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Abstract

D. Maier (2014) compiled the image band rejections of the 2 mm EMIR mixers as measured in the IRAM/Grenoble laboratory. These show rejections of −10 dB or better, and on average about −13 dB. Here, an attempt was made to derive image band rejections at the telescope for EMIR band E150 from spectral line surveys of the evolved star IRC+10216. During commissioning of the newly installed dual-sideband mixers in October 2013 a shallow frequency survey was conducted. These data are compared with newer data taken in October 2014, as part of project 013-14 (PI: M. Guelin). Spectra of the simultaneously observed lower and upper sidebands are used to identify in a semi-automatic way lines from the signal and image bands. More than 20 lines have been identified in the signal bands between 120 and 160 GHz. For the survey of October 2013, all rejections are at least −10 dB or better, independent of polarisation, and about consistent with the laboratory measurements. In contrast, the survey of October 2014 shows strongly degraded image band rejections for the vertical polarisation; gain ratios are as poor as −3 dB over a wide frequency range. Gain ratios of the horizontal polarisation are better, but also degraded.
We discuss any variations of the gain ratios with cold head temperature inside the cryostat, with LO frequency, and with mixer bias. The observations of October 2014 show a marked dependence on the LO frequency. Furthermore, dedicated test observations on 28-March-2015 show that decreasing the mixer bias systematically improves the observed gain ratios. It is noted that the tuning tables had been revised in the course of 2014. To supress oscillations, mixer bias values had been increased.

Method

For a strong celestial line in the signal band, the same line will appear in the image band but reduced in intensity depending on the image rejection. With the dual-sideband (2SB) mixers of EMIR and the wideband fast fourier transform spectrometers (FTS), both sidebands can be observed simultaneously. Figure 1 shows example spectra observed simultaneously with the lower inner and the upper inner sidebands. Lines are detected in both signal bands, and leak through into their respective image bands. Spectral surveys of sources rich in strong lines like IRC+10216 do provide a possibility to infer image band rejections over a range of frequencies from on-sky observations.

For pairs of simultaneously observed lower and upper sidebands, in a first step all lines present in any of the sidebands are identified. For the line identification, the spectrum is summed piecewise over the number of channels corresponding to the expected linewidth (Cernicharo et al. 2000: shell expansion velocity 14.5 km/s; here 31 km/s is used for the full linedwidth). Maxima in the sum spectrum above a threshold of 3 r.m.s. are considered as detected lines, where false identifications may occur for very close or overlapping lines, or lines with deviating linewidths. In a second step, for each detected LSB line it is checked whether a line was detected in the USB whose image frequency equals the signal frequency of the LSB line (maximum deviation two times the channel width). The image band rejection is calculated from the ratio of the line integrals, where the signal band is considered to be the sideband in which the line is stronger. For lines present in one sideband without a counterpart in the other, a limit for the image rejection is estimated assuming that the image line is weaker than 3 rms and therefore undetected. A CLASS script is available to identify lines and derive image band rejections (but requires visual inspection of the potentially matching line pairs to sort out false identifications). [1] This identification of signal/image line pairs is repeated separately for each spectral setup (i.e. tuning frequency), both subbands (inner/outer) and polarizations (horizontal/vertical).

[1] Currently no check is included to rule out by-chance alignment of two real lines from USB and LSB, since the probability for this is considered low (but could be added later if necessary).

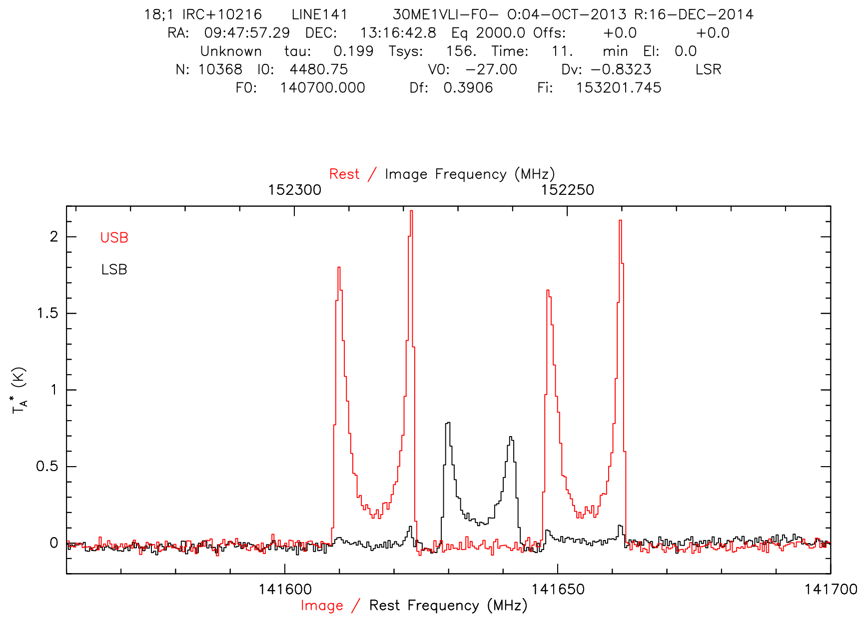

Figure 1: Overlay of IRC+10216 spectra of the lower inner sideband of E150 (LSB, black) and of the upper inner sideband (USB, red), where the lower frequency axis is in terms of rest frequency for the first and in image frequency for the second. For the two outer lines (where USB is the signal band), lines at the same position damped by about −14 dB are visible in the LSB. For the middle line (with LSB the signal band), the absence of a corresponding line in the USB is likely due to the limitation by the baseline noise, allowing to give a lower limit to the image band rejection. (Spectra smoothed by factor 2 for improved visibility.)

Results

October 2013

Resulting gain ratios from the IRC+10216 spectral survey conducted in October 2013 (see Appendix) are shown in Figure 2. The survey covered 122.7–188.3 GHz (in six setups with LO frequencies 134.43, 139.25, 146.95, 162.25, 170.25 and 176.57 GHz), of which only the range up to 160 GHz is considered in the following because of strongly increasing baseline noise beyond this frequency. About 120 lines above 3 r.m.s are identified for each polarization over the whole frequency range, including lines which are detected multiple times because of frequency overlap between inner/outer subbands or the different tunings, and including image lines which are leaked through from the signal band to the image band. Only few lines with matching signal/image frequency are detected above 3 r.m.s both in signal and image band: six in vertical polarization (of which two lines are detected twice, in the inner and outer subband of the same tuning frequency, yielding image rejections consistent within 0.3 dB), and one in horizontal polarization (shown as filled circles in Figure 2). Upper limits are shown only for image rejections < -10 dB (i.e. derived from lines $>$30 r.m.s). The increase of the lowest upper limits with frequency is due to the increase of the baseline r.m.s.; with strongest lines of ≈15 K and lowest r.m.s. of ≈0.03 K no image rejections below −23 dB are detectable.
All measured image rejections (i.e. line detected both in signal and image band) are located between −10 and −20 dB, upper limits on the image rejections are as low as −22 dB, comparable with the laboratory measurements of E150. In all cases where a measurement is possible in one polarization, the signal line appears at comparable strength in the other polarization, but the image line is undetected at a level of 3 r.m.s. (corresponding to upper limits on the image rejection of 1–6 dB lower than the measured value in the other polarization). Hence, at least for these lines, the image band rejection tends to be slightly better in the H polarization, also in agreement with the laboratory measurements.

October 2014

Results for IRC+10216 observations conducted in October 2014 under project 013-14 are shown in Fig. 3. This survey covered the frequency range 125.4–160.6 GHz in eight setups with LO 137.181–148.953 GHz,

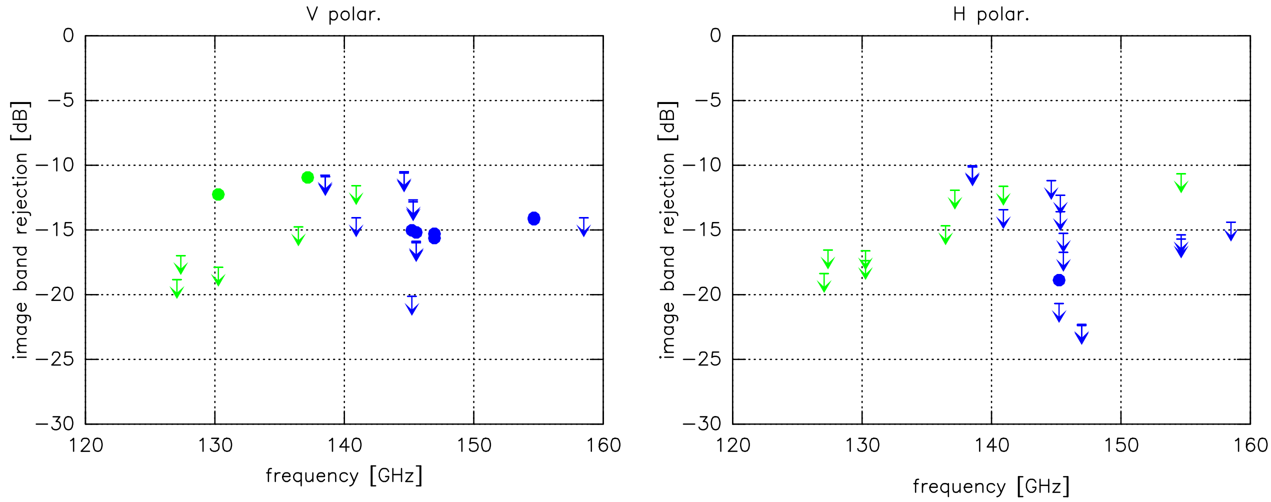

Figure 2: Image band rejections for 2013 survey of IRC+10216: lines stronger than 3 r.m.s. in both signal and image band were taken into account (filled circles), upper limits of the image band rejections (arrows) are shown only for lines where a limit of < -10 dB is derived. Values from the LSB (i.e. the signal line is detected in the LSB, and the damped image line in the USB) are shown in green, values from the USB in blue.

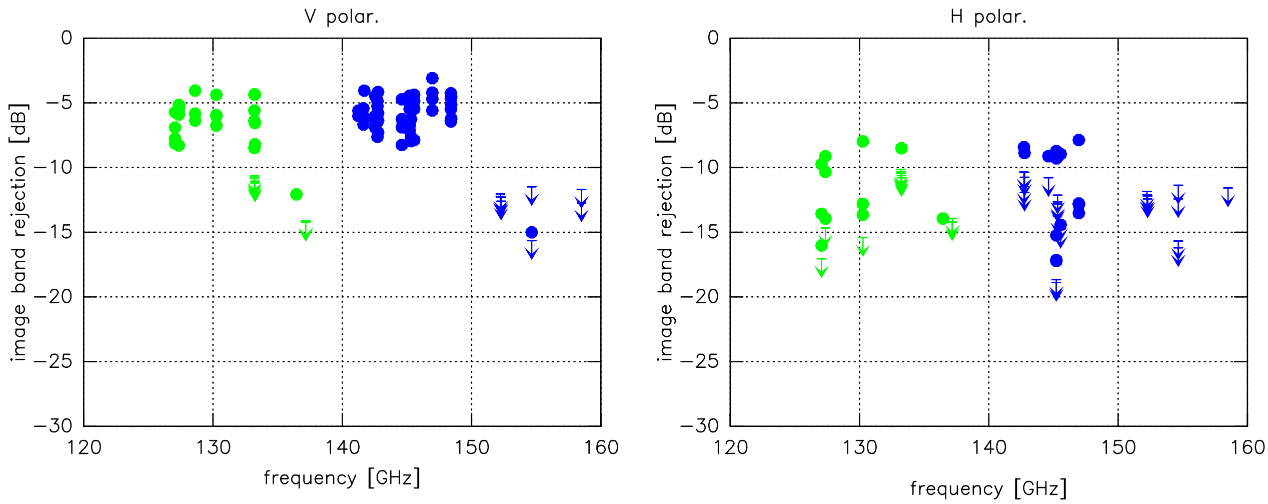

Figure 3: Image band rejections for 2014 observations of IRC+10216: lines stronger than 3 r.m.s. in both signal and image band were taken into account (filled circles), upper limits of the image band rejections (arrows) are shown only for lines where a limit of < -10 dB is derived. Values from the LSB are shown in green, values from the USB in blue.

with setups being partially spaced by only 50 MHz, so that many lines are covered by several frequency setups (each of these measurements is shown as individual point in Fig. 3; in addition, some lines are detected in the overlap region between outer and inner subband of the same frequency setup, therefore also yielding two measurements). In contrast to the results from 2013, significantly poorer image band rejecetions are found, especially for the vertical polarization (up to -3 dB, 24 individual lines with detection in LSB and USB, yielding 73 measurements; in horizontal polarization, 11 individual lines yield 26 measurements with rejections up to -7 dB). An example is shown in Fig. 4. The dependence of the rejections on the frequency setups for the vertical polarisation is shown in more detail in Fig. 6: the poorest rejections are found for LO 137.331 GHz, and better ones for both higher and lower tuning frequencies. It should be noted that for the next closest setup, 137.281 GHz, spectra in H (but not V) show spurious features (see Fig. 5). A further illustration of lines observed with different frequency setups is given in Fig. 7.

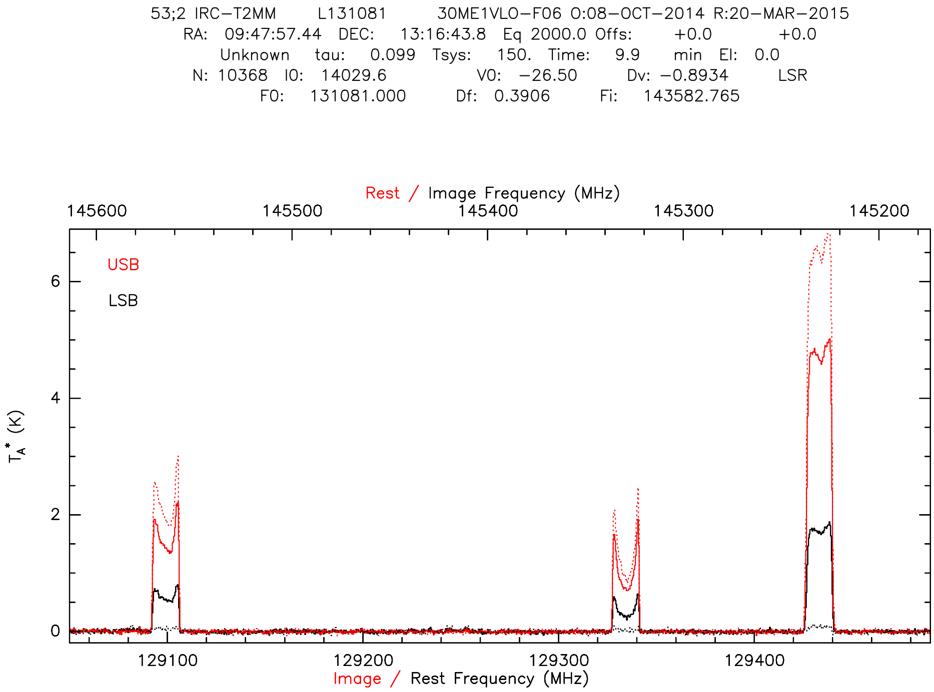

Figure 4: Overlay of IRC+10216 spectra from 2014 (LO 137.331 GHz). The vertical polarization is designated with solid lines, the horizontal with dotted lines. Differences in the signal line strength (USB, red) between both polarizations are apparent; the different strength of the image lines (LSB, black) is even more pronounced: image band rejections are ca. -4 dB in V, in H only upper limits of < -12 dB are obtained. (Spectra smoothed by factor 2 for improved visibility.)

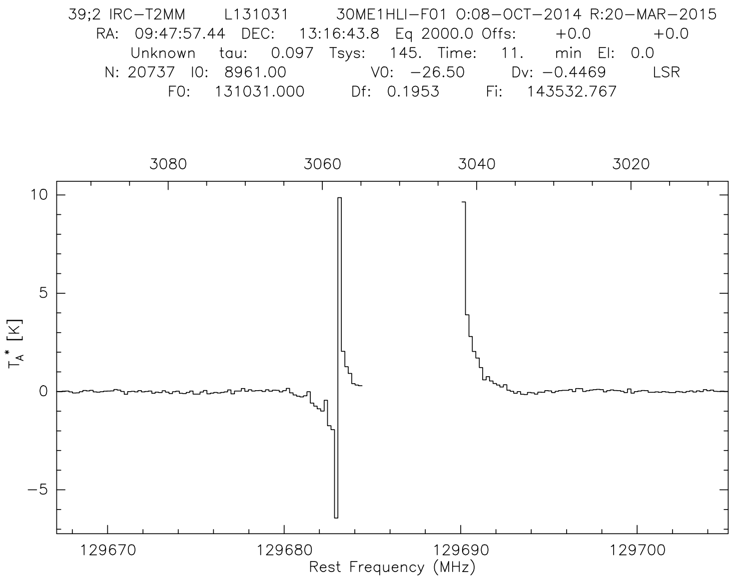

Figure 5: Spurious feature on HLI for tuning with LO 137.281 GHz (IRC+10216, 2014). Comparable features are seen in H outer band, but not in vertical polarization.

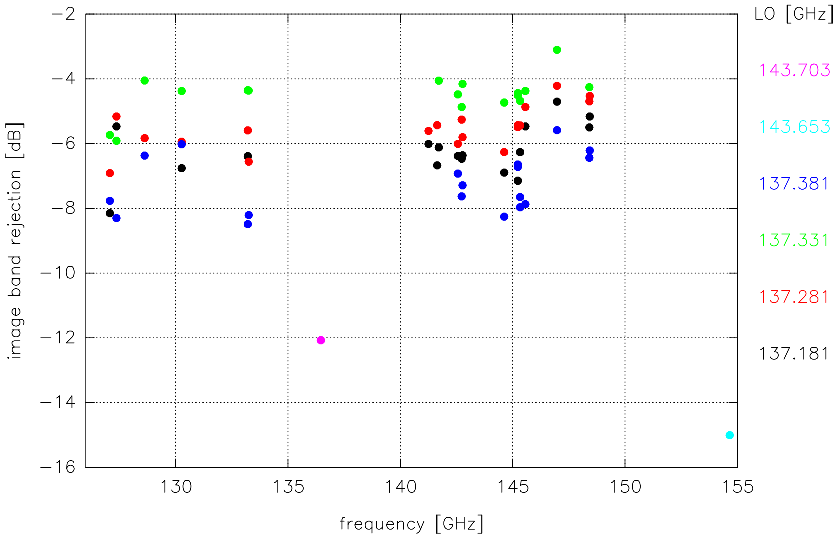

Figure 6: Image band rejections for 2014 observations of IRC+10216 in vertical polarization, colour-coded for six setups with different LO frequencies. The poorest image rejections are observed for the setup with LO 137.331 GHz, better rejections are found for both lower and higher tuning frequencies.

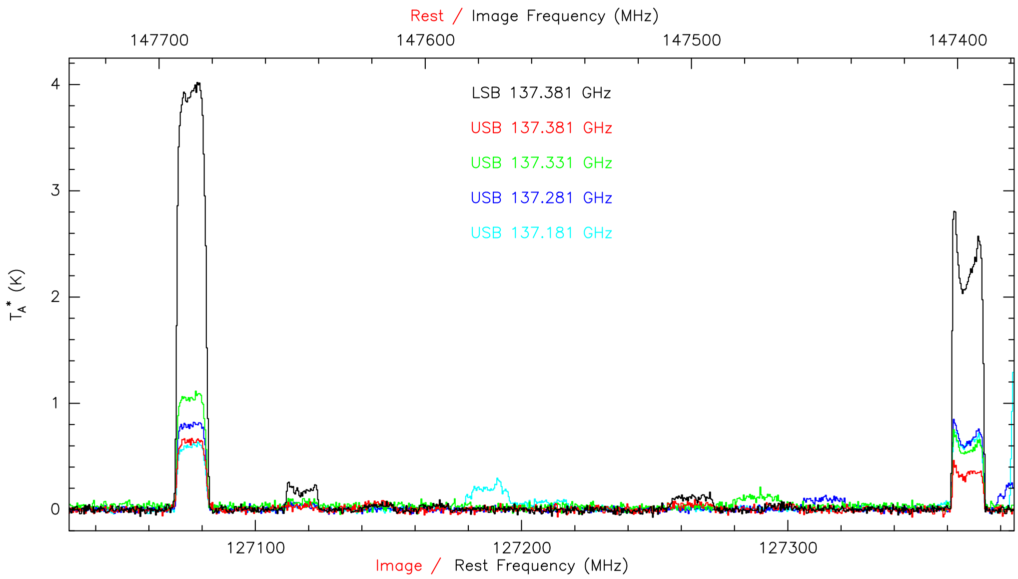

Figure 7: Example of two signal lines (127.075 and 127.367 GHz, with vertical outer LSB the signal band) observed with four frequency setups (LO 137.381, 137.331, 137.281 and 137.181, respectively). The signal lines are shown in black (peak of the 127.075 GHz line is somewhat different with 4.05, 3.56, 3.91 and 4.00 K for the four frequency setups; the temperature scale is shown for setup LO 137.381 GHz while the other spectra have been scaled such, that the signal lines appear at same strength). Coloured lines show the image lines, which depending on the line frequency and frequency setup are damped to different amount with respect to the original signal lines. In this example, the best image rejections are seen for the LO 137.381 setup (ca. −8 dB for both signal lines). For the 127.367 GHz line, the other three setups yield similar, somewhat poorer rejections of −5 dB, while for the 127.075 GHz line, the rejections spread from −6 to −8 dB.

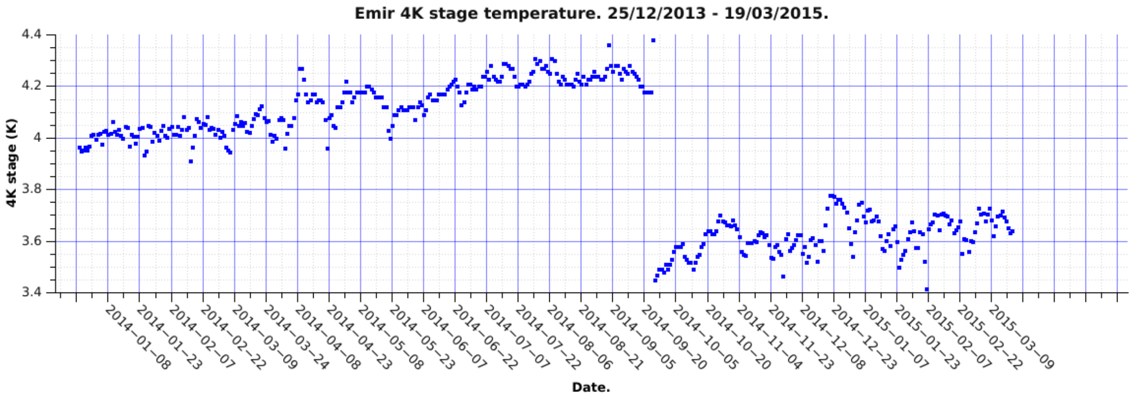

Figure 8: Variation of the cold head temperature.

1 Cold head temperature

Figure 8 shows the variation of the cold load temperature between end of 2013 and October 2014. The temperature gradually increased till heavy maintenance in September 2014, and then dropped by 0.8 K.

2 Varying the mixer bias

On 28-March-2015, test observations on IRC+10216 were carried out at 143 GHz UI. The mixer bias was varied by ±0.2 mV relative to the tuning table. The observations (Fig. 9) show that the gain ratios systematically improve when decreasing the mixer bias, and degrade when increasing the bias. The variation is about ±2 dB. For these observations, the poorest image band rejections are −8 dB.

3 References

- Cernicharo, Guelin, Kahane; 2000; A&ASS, 142, 181
- Kramer, Navarrini, Navarro, John, Cernicharo; August 2014; IRAM Report on EMIR ghost lines (unwanted harmonics of the local oscillators)
- Maier; June 2014; IRAM Report on Lab measurements of EMIR receivers: receiver temperatures and image band rejections

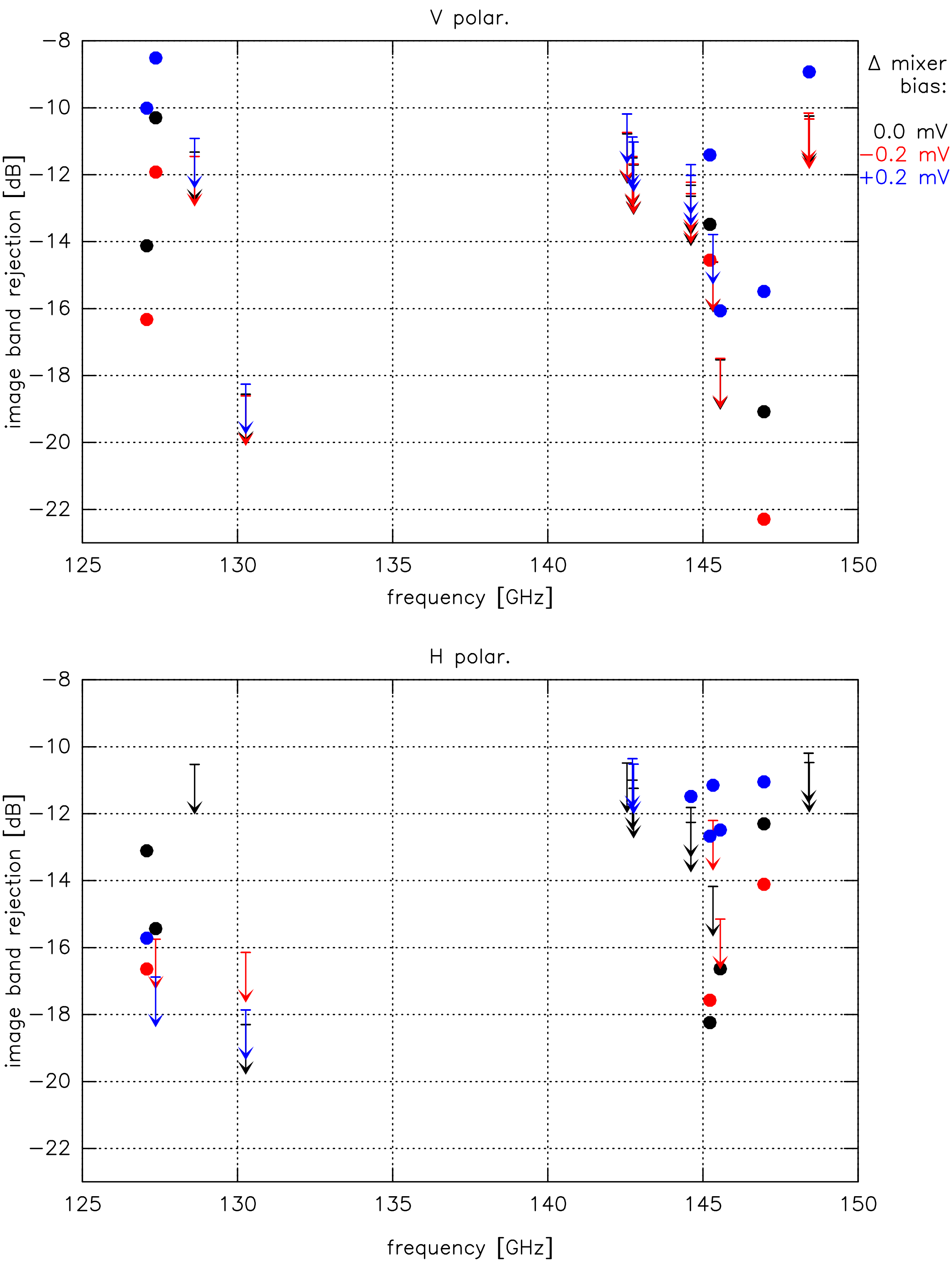

Figure 9: Variation of gain ratios with mixer bias in test observations of 28-March-2015.

4 Appendix: 2mm survey of IRC+10216 in October 2013

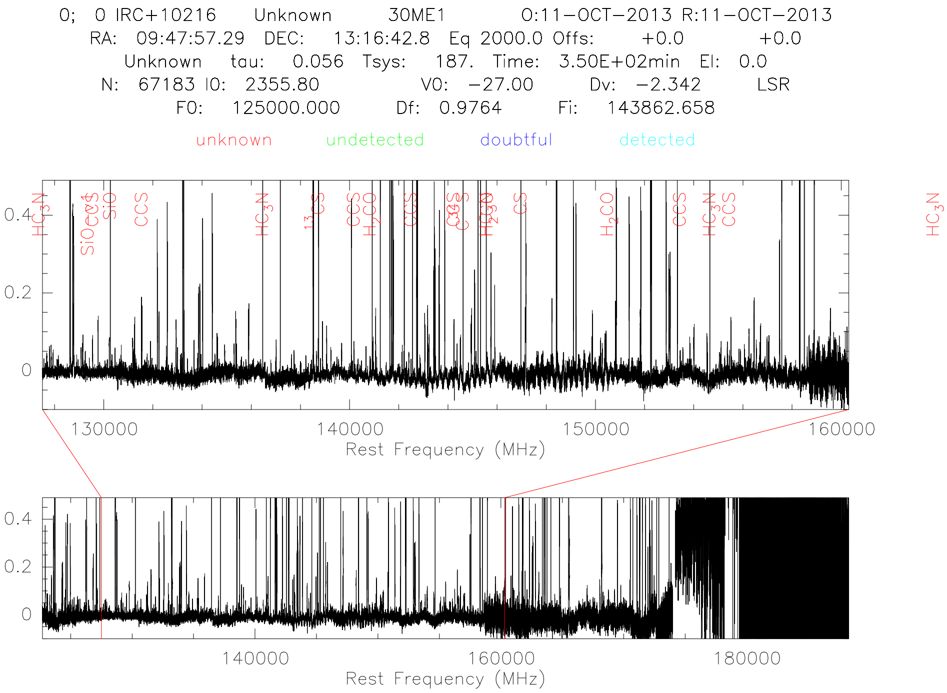

Figure 10: Frequency survey on IRC+10216 with E150 in October 2013.

Figure 10 shows the 2mm frequency survey on IRC+10216 which was conducted with the upgraded 2mm E150 mixers of EMIR on 4/5/6-October-2013. We used E1 only, with both 8 GHz wide sidebands, with the FTS at 200 kHz resolution. Observations were done in onoff mode with the reference 5' offset in Azimuth. Weather conditions varied between 10mm and 6mm of pwv. The lower and upper outer 4GHz bands of the survey were 125 GHz and 186 GHz, for which the tuning went without problems.
Only 1.order baselines were subtracted from the individual FTS units. The stitched spectrum was smoothed to 1MHz resolution, to compare with the 2mm survey of Cernicharo et al. (2000, CGK00). For the upper end of the frequency range the atmospheric calibration failed due to a strong atmospheric water line near 183 GHz. For those frequencies, we recalibrated spectra in mira with a fixed, best-guess value of the water vapor of 6 and 10mm. Note, however, that the baseline noise rises steeply at the high frequency end.
CGK00 took great care to measure the sideband ratio, Gim, and correct for it. When comparing antenna temperatures measured now and then, the data have to be corrected for the improved beam efficiencies between before 2000 and now. CGK00 used a constant Beff/Feff of 0.6. The values of today are: Beff/Feff = 0.74/0.93 = 0.80 at 145 GHz (see the IRAM 30m homepage).
We compared main beam temperatures for a few lines. The ratios of Tmb temperatures, of 2013 over those of 2000, show on average a discrepancy of only 11%, and the mean is near 1:
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HC3N 136.46GHz 0.96
HC3N 145.56GHz 0.86
HC3N 154.66GHz 1.06
HC3N 163.75GHz 1.19
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To improve the calibration accuracy further, we could in the future take into account (1) the slight variation of the beam efficienciy over the large frequency range, (2) correct for the (small) variation of the efficiency with elevation (gain-elevation curve) at 2mm, and (3) try to measure and correct for any variations of the sideband gain ratio. The latter point is addressed in the main part of this report.