EMIR ghost lines

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Contents

Abstract The EMIR local oscillators (LOs) do create harmonics of its Gunn oscillators, which are mixed in the sideband separating mixers, and then down converted into the IF (intermediate frequency) band. The LOs do, however, also create unwanted harmonics which may not be sufficiently suppressed, leak through, and pump the mixers. This may lead to detections of ghost lines stemming from much higher frequencies, far outside the nominal frequency range, polluting the observed spectra. Such lines have recently been identified in frequency surveys of IRC+10216: in one example, a ghost line showed-up at 129 GHz in the E150 band, which does however stem from a line at 196 GHz. With the large bandwidths provided by EMIR, and with deep frequency surveys on Galactic sources, addressing these ghost lines becomes important. This report intends to inform observers of the current status of this issue, describe the origin of the harmonics, give observational examples showing also how to detect ghosts, and describe counter measures which are currently being prepared by the IRAM frontend groups.

1 EMIR local oscillators and mixers

Each of the four EMIR bands has one local oscillator (LO) to pump the mixers of both polarizations (Carter et al. 2012). Each LO consists of a Gunn oscillator which provides the fundamental frequency $\nu_{\rm fund}$, a multiple of which is the local oscillator frequency $\nu_{\rm LO}$ which is mixed with the sky radiation in the SIS mixers. All Gunn oscillators work in second harmonic, i.e. the doubled fundamental oscillation is used further. EMIR bands E150, E230, and E330 next have a multiplier to create the final $\nu_{\rm LO}$. E150 has a doubler, while E230 and E330 have a tripler multiplier. E090 has no multiplier.

Next to the 2nd harmonic of the fundamental frequency, the Gunn oscillators also create higher order harmonics (3rd, 4th, etc.). These are spurious and we would like them to be rejected. These harmonics are injected into the multipliers, which in turn, also create higher order (unwanted) harmonics. In case the power of all these unwanted harmonic frequencies is sufficiently high, they may be able to pump the EMIR mixers, which means that this signal is down-converted into the intermediate frequency (IF) bands. This may increase the receiver noise, and may lead to detection of spurious ghost lines.

The unwanted harmonics are to some degree rejected by different means. Waveguides for example have a cut off frequency below which oscillations are not transmitted. The basic design of the multipliers of Virginia Diodes (VDI) use symmetry to reduce the number of unwanted harmonics. For example, in a doubler the odd harmonics of the LO are at least to some extent suppressed by the symmetry.

The sideband seperating mixers (2SB) which are now in use for all EMIR bands have several advantages with respect to the previous generation of backshort-tuned mixers: two IF outputs rather than only one, twice as much bandwidth on each of the two, constant image sideband rejection versus IF frequency (as opposed to degraded rejection towards the IF band edges), better input match at the radio frequency (RF) input, higher saturation power. However, one of the advantages of the backshort-tuned SIS mixers of the previous generation of receivers at the 30m telescope was the better rejection of the unwanted harmonics of the local oscillator: the mixer backshorts could be set to reject to a very low level the LO harmonics. The current generation of 2SB SIS mixers do not provide strong intrinsic rejections of the LO harmonics.

Higher order harmonics created by the LO of one EMIR band may be detected by other EMIR bands.

2 Observational example

In October/November 2013, new dual-sideband (2SB) mixers have been installed in the 2mm band of EMIR. During commissioning, a frequency survey of IRC+10216 was conducted. Careful investigation by Pepe Cernicharo have only recently revealed a number of spurious lines which show the characteristic double-peaked line profile of this source.

A spurious has been identified near 129.144 GHz. A very nice line is detected at this frequency (see the upper left plot of Fig. 1). The LO frequency of this observation was set at 134.431 GHz, the IF was at 5.287 GHz, and the USB was at 139.718 GHz. The detected line is neither from the image side band nor from the signal side band as it is not present in the 2mm line survey of Cernicharo et al. (2000) of IRC+10216 in any of the bands, LSB 129.144 GHz or USB 139.718 GHz. The latter survey had been done with SSB mixers with backshort, while the new survey with EMIR was done with 2SB backshort-less mixers.

The line is in fact too broad, $45\,\mathrm{km\,s^{-1}}$ rather than the nominal $29\,\mathrm{km\,s^{-1}}$ of most lines of this source, i.e. about a **factor 1.5** larger. It is certainly coming from a frequency roughly **1.5 times larger**. The line was observed at both polarizations with about similar intensities (Fig. 1 upper left).

From the line shape it is not CS, SO or SiS (SO does not exist in this source). The best candidate is the line of SiC2 with quantum numbers $826 - 725$ and frequency 196.359070 GHz. This line should be around 1.5-2 K in intensity.

The best explanation is that this line is caused by the **third unwanted harmonic** of the VDI doubler pumped by the wanted Gunn frequency at 67.2155 GHz (Gunn fundamental frequency at 33.6077 GHz). A second possible explanation would be that the second (wanted) harmonic of the doubler is pumped by the (unwanted) third harmonic of the Gunn fundamental.

Many IRC+10216 spectra taken at frequencies below 130 GHz, show features coming from higher frequencies. They are all weak, less strong than the one at 129.144 GHz line but all of them have a linewidth which is too large. From the shape they correspond to SiS and SiO (perhaps also CS) isotopologues.

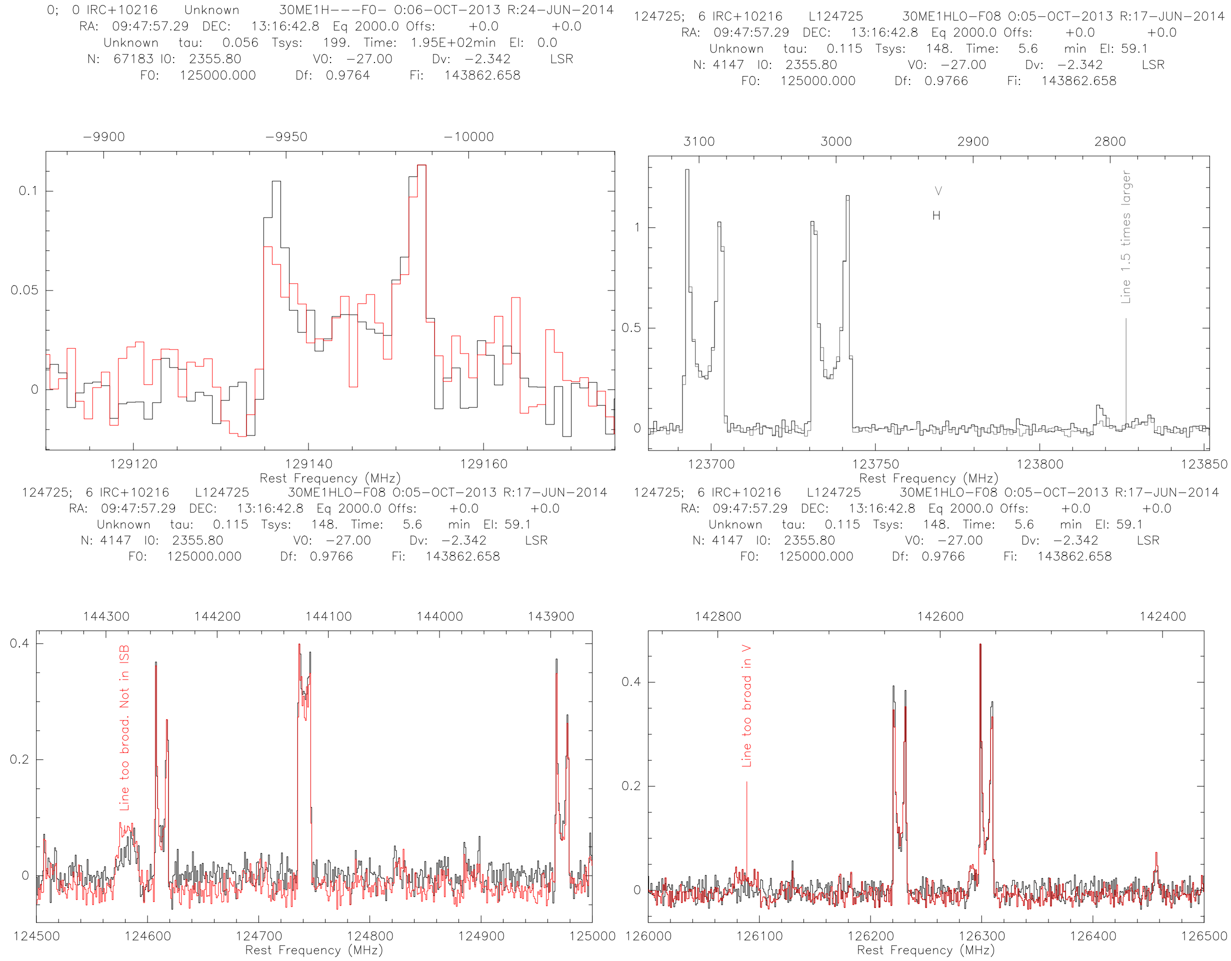

Figure 1: **Upper left:** Ghost line near 129.144 GHz, about a factor 1.5 too broad, probably stemming from a transition of SiC2 at 196.359 GHz, at a factor 1.5 higher frequency. The vertical polarization is plotted in red, the horizontal in black. **Upper right:** Ghost line near 123.825 GHz a factor 1.5 larger than the nominal width. **Lower left:** Too broad ghost line near 124580 MHz. The two polarisation are plotted in red and in black. **Lower right:** Too broad ghost line near 126080 MHz.

3 Identification of Ghost Lines

Below, we describe a number of possibilities which all together provide means to identify ghost lines, their corresponding harmonics, and their corresponding species and transitions.

Here, we use the term *ghost line* for spurious, unwanted lines which are created by unwanted harmonics of the local oscillator. The ideas listed below should also allow to distinguish ghost lines from other spurious lines or from truely unidentified interstellar lines.

Table 1 shows the harmonics of the local oscillator chains of the four EMIR bands:

The E150 observations described above, show a ghost line stemming from a frequency a factor 1.5 above the nominal frequency, i.e. a factor 6/4 with the final multiplication factor $F = 6$ instead of 4 (cf. Table 1).

1. The **line shapes** of ghost lines will resemble those of the source. Especially in the case of the characteristic line profiles of IRC+10216, this helps to distinguish ghosts from other spurious features created by

	L	N	$F = L \times N$
E090	2	1	2
E150	2	2	4
E230	2	3	6
E330	2	3	6

Table 1: Harmonics of the EMIR local oscillator chains. The Gunn output provides the 2nd harmonic of the Gunn fundamental frequency $\nu_{\rm fund}$. And the multipliers of E150, E230, E330 provide the 2nd and 3rd ($N = 2, 3$) harmonic of the Gunn output frequency. The local oscillator frequency is $\nu_{\rm LO} = L \times N \times \nu_{\rm fund}$. Higher order (and also lower order) harmonics than those listed are unwanted. What matters is the ratio of unwanted over wanted final multiplication factors, $F_{\rm unwanted}/F_{\rm wanted}$.

the internal RF and IF electronics. It does however not help to distinguish ghosts from weak, unidentified interstellar lines.

2. LO: **Moving the LO frequency** slightly by $\Delta\nu$ does not require re-tuning, but allows to identify whether the observed line is a ghost and which harmonic creates it. A line created by mixing with the wanted harmonic of the Gunn, will **not** move in sky frequency. However, a ghost line will move in sky frequency which allows to get a hint on the (unwanted) harmonics.

   For example, if the line moves by a factor 1.5 and the wanted final multiplication factor is 4 (like for E150), the unwanted final multiplication factor creating the ghost line is $1.5 \times 4 = 6$, indicating that either the 3rd harmonic of the Gunn fundamental or the 3rd harmonic of the doubler cause the ghost.

   Note that shifting the LO is also a powerful, often used method of itentifying lines from the image sideband.

3. FWHM: Ghost lines will have a **width** which is broader than the nominal width expected at a given sky frequency by again the factor $F_{\rm unwanted}/F_{\rm wanted}$, e.g. 6/4 for E150 when the ghost stems from the 3rd harmonic.

4. True frequency: To determine the **frequency of the transition and species** emitting a potential ghost line, the true frequency, the observer has to read the sky frequency of the line $\nu_{\rm sky}$, the tuned frequency from the CLASS header ν_0, and the tuned sideband (LI, LO, UI, or UO). The band centers lie at the IF frequencies $\nu_{\rm IF,cen}$ -9.43, -6.25, $+6.25$, $+9.43$ GHz (cf. EMIR homepage).

   For example, the ghost line detected at $\nu_{\rm sky} = 129.144$ was observed with $\nu_0 = 125.000$ tuned to the lower-outer (LO) band, and hence $\nu_{\rm LO}$=ν_0+$\nu_{\rm IF,cen}$=134.431 GHz. The ghost line was hence observed at $\nu_{\rm IF}$=$\nu_{\rm LO}$-$\nu_{\rm sky}$=5.287 GHz in the lower inner band with the upper sideband frequency of $\nu_{\rm sky} + 2 \times \nu_{\rm IF}$ = 139.718 GHz.

   So far, there is nothing unusual. Where does now the ghost line come from ? It stems from a sky frequency about $F_{\rm unwanted}/F_{\rm wanted} = 6/4$ times higher and probably from the same sideband, as the image sideband is rejected by the gain ratio of about -13 dB. More exactly, it stems from $\nu_{\rm sky,ghost} = \nu_{\rm LO} \times F_{\rm unwanted}/F_{\rm wanted} - \nu_{\rm IF}$ = 196.359 GHz in the above example.

4 Running investigation and next steps

Better Characterization of current status. We will try to better characterize the current situation: which harmonics are detected and at which level.

- New laboratory test measurements by Mattiocco et al. (July 2014) show that the 3rd and 4th harmonic of the doubler of E150 are detected, as well as the 3rd and 4th harmonic of the Gunn fundamental of E090. The 5th harmonic is not detected. They note that outside of the nominal RF band, the 2SB mixers will have zero or little rejection.

- For this, we plan for on-sky test time on IRC+10216, to measure the rejection of the 3rd harmonic with E150, and the 4th harmonic with E230, by injecting artificial lines.

- We also plan to check whether higher harmonics of the fundamental Gunn frequency $\nu_{\rm fund}$ leak through.

- We have started to check the mixer I/V and conversion curves for features indicating pumping of unwanted harmonics.

Future improvement. In addition, we will try to improve the suppression of unwanted harmonics on EMIR, but also on the new receivers for NOEMA. We have started to design waveguide filters to reject the unwanted harmonics of the LO to a level where they cannot pump the 2SB SIS mixers and hence are not down-converted into the IF band. The filters required at the multiplier outputs are band-pass filters across the entire LO bands.

For example for E1, the filter would need to let pass the tuning range of LO frequencies, but suppress at the lower frequency edge the third harmonic of the Gunn fundamental, and the upper edge the third harmonic of the doubler.

We may need to construct filters for all four EMIR bands.

This is an ongoing effort. We will inform the observers of any major steps forward.

5 References

- Carter et al. 2012, A&A, 538, A89 “The EMIR multi-band mm-wave receiver for the IRAM 30m telescope”

- Francois Mattiocco, Julien Reverdy, Doris Maier, Alessandro Navarrini, 24-July-2014, IRAM report “NOEMA Band 1 and Band 2 2SB SIS mixers pumped by unwanted harmonics of the local oscillator”