EMIR Commissioning Report

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Here, we report on the commissioning of the new Eight Mixer Receiver, EMIR [1], at the IRAM 30m telescope in April 2009. As already reported by S.Navarro [2], the observed alignment between the beams of the two polarisations and between the bands is very good. We derived telescope efficiencies from observations of Mars and from skydips, which show that the coupling of the EMIR beams to the telescope is as expected. The measured aperture efficiency at 330 GHz is 30%. All EMIR frequency setups of Bands 1 to 3, which had been requested for the coming summer semester, were tested. Spectral line observations were conducted using the WILMA, 4MHz, and VESPA backends, using all standard observing modes. 3mm VLBI was tested together with the PdB and works well. Commissioning of Polarimetry with EMIR is planned for mid June, and commissioning of Band 4 is planned for October/November.

The large bandwidths provided by EMIR, required to strongly change the IF distribution at the 30m telescope. Inside the receiver cabin, an IF switch box was installed, to select 4 outputs of 4GHz to be sent via new IF cables to the backend room. Three new processors, the 4MHz processor, the 4x4 WILMA processor, and the Narrow Backend Processor, were built to distribute the signals finally to the known set of backends. During commissioning, a problem with the WILMA switches (contact glue) to combine signals from HERA and EMIR, had to be addressed and is now solved.

Major parts of the software had to be rewritten for EMIR. This concerns part of the "New Control System" and, of course, the PaKo user interface. In addition, the entire software producing the data had to be thoroughly revised: the read-out of the spectrometers into data streams, the transformation into IMBfits raw data, and the final transformation into calibrated data on the antenna temperature scale. As a simulation of the entire system before installation was not possible, a significant part of the commissioning period was spent debugging this software. As weather conditions were poor most of the time, only a limited number of science observations could be obtained. But note the deep integration on the Cloverleaf quasar, yielding flat baselines with 32GHz bandwidth at 0.4mK rms, after only few hours of integration time.

Routine observations with EMIR started on April, 28, without encountering major obstacles since then.

This report is focussed on the results of the commissioning weeks. See the following documents on a thorough characterization of EMIR in the Grenoble lab, the report on the installation at the 30m telescope, and the Users Guide:

- **[1] EMIR receiver characterization in the laboratory** by A.L.Fontana (3/2009)
- **[2] EMIR Installation report** by Jean-Yves Chenu, A.L. Fontana, B.Lazareff, P.Pissard, D.John, J.Penalver, and Santiago Navarro (2.4.2009, V1.0)
- **[3] EMIR Users Guide** by Clemens Thum, Karl Schuster, Carsten Kramer http://www.iram.es/IRAMES/mainWiki/EmirforAstronomers

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1. Continuum observations.

1.1 Continuum backends

At present, only the central 1GHz of each 4GHz chunk are being used for continuum detection. Broad band 4GHz wide continuum detectors are in preparation.

1.2 Nasmyth offsets.

EMIR has two beams separated by 90” on the sky. Several pointing sessions were conducted to determine the Nasmyth offsets to be -39.0"/+5.5" for the right beam and +51.0"/+5.5" for the left beam. Each pointing session consisted of observations of several dozen of point sources distributed over the sky. The right beam is used for single band E0 or E2 observations, and for dual band E0/E2 and E0/E1 observations. The left beam is used for E1, E3, E1/E3. At present, the observer has to set the Nasmyth offsets in PaKo. They are not yet set automatically when switching the EMIR setup.

1.3 Alignment.

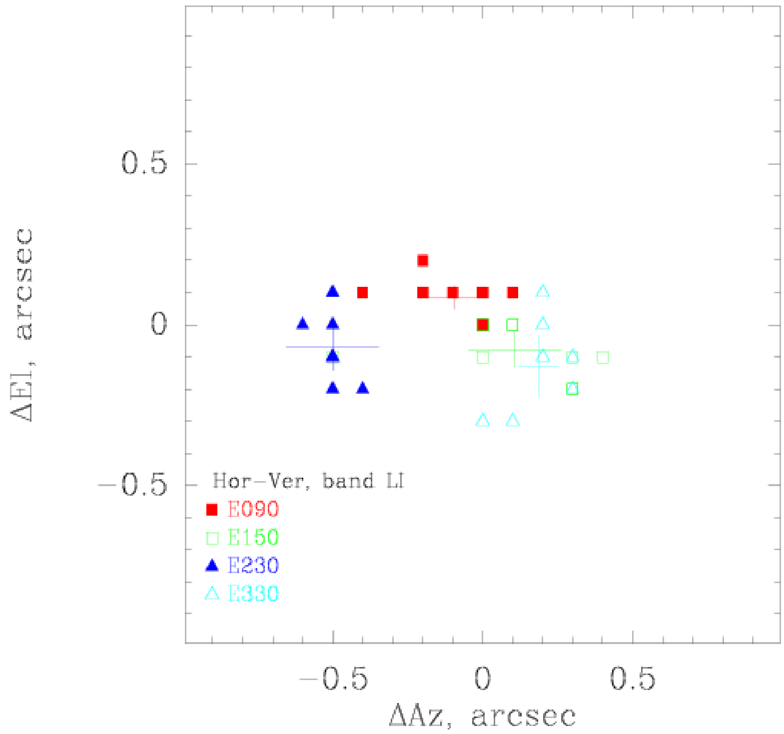

Figure 1: Alignment measured on Saturn

Saturn and Mars have been used to measure the alignment between the 8 beams of EMIR. Here, we present two sets of data taken at two dates, on Saturn and on

Mars. These data indicate that the alignment between all beams is better than about one arcsecond.

Saturn observations (Figure 1) indicate a very good alignment between all beams of EMIR. Note that in particular the alignment between the two 3mm polarisations is better than a few 0.1 arcsec, which is important for polarimetry. But note also that Saturn had a diameter of ~18 arcsec.

Mars is more pointlike with 4.3 arcsec diameter on March 29th. Mars observations (Figure 2) indicate that the alignment between E1 and E3 is better than ~0.3 arcsec, while the alignment between E2 and E0 is roughly 1 arcsec. (But note the Mars observations presented in Figure 8 of [2], which indicate an E1/E3 alignment error of 1.6”.)

More Mars observations under excellent weather conditions are needed to derive more firm statements.

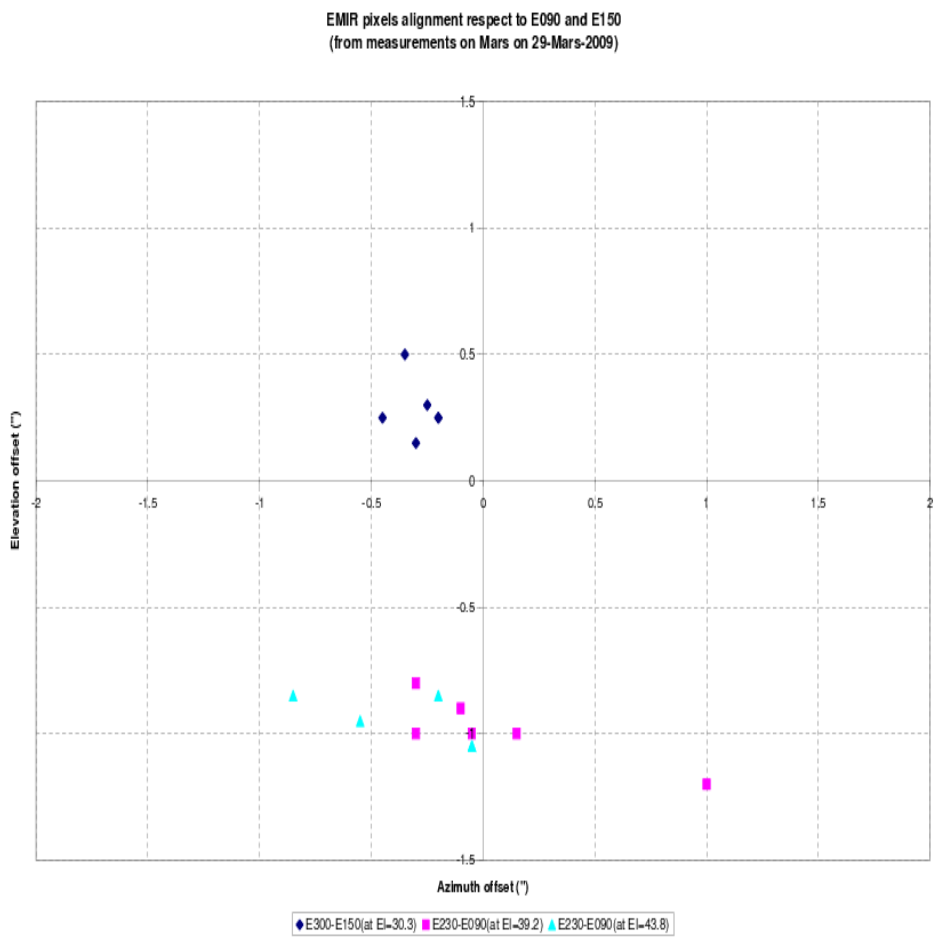

Figure 2: Alignment measured on Mars (29.3.09).

1.4Focus Positions.

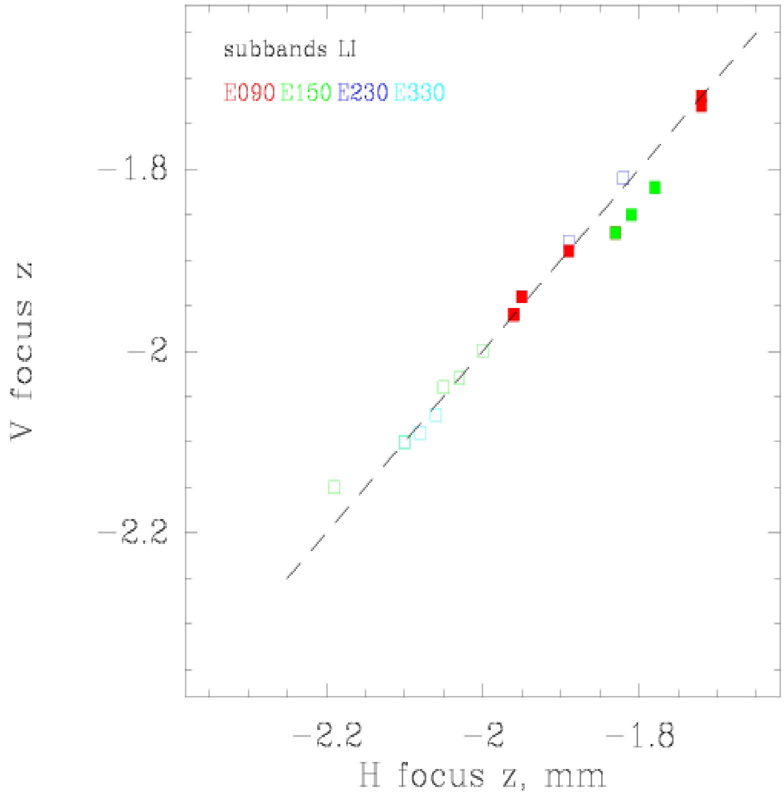

Figure 3: Focus positions for the two polarisations.

The above figure shows the focus between different polarisations of the same band. There are no significant differences between these foci.

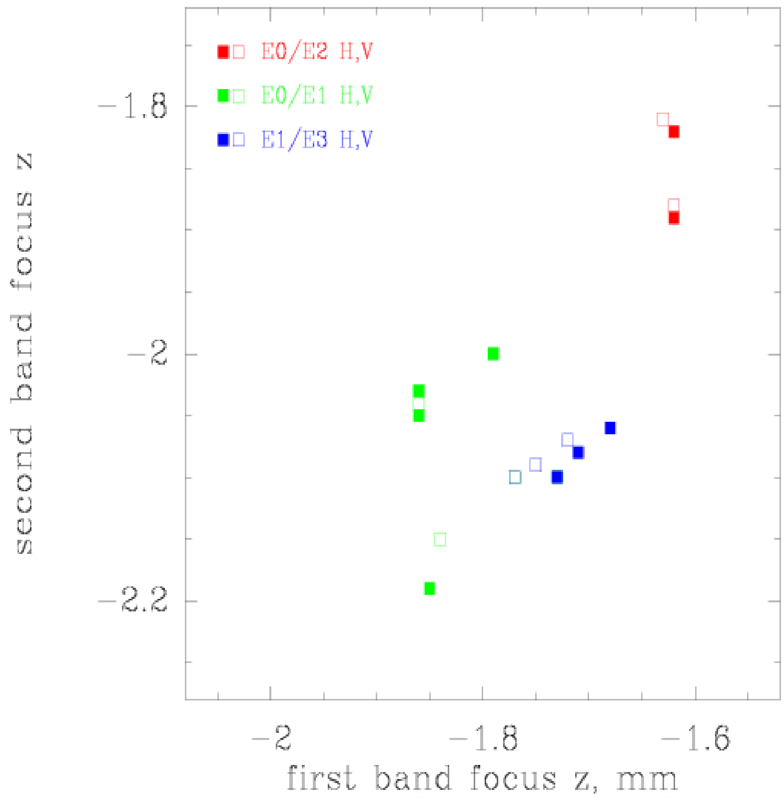

Figure 4: Focus positions for the four EMIR bands.

Figure 3 shows the focus between different bands. The largest deviation is about 0.3 mm, similar to the situation with the ABCD receivers. For dual band observations, the telescope should be focussed to the high frequency band.
We also made focus scans in lateral (x, y) directions, however, with inconclusive results. The observed telescope efficiencies indicate that the telescope is well focussed in x,y,z.

1.5 Telescope efficiencies.

Freq	HPBW	Feff	Beff	Aeff	S/TA*	Date
GHz	arcsec	%	%	%	Jy/K	
86	29	95	81	63	5.9	4.4.
145	16	93	74	57	6.4	4.4.
210	11	94	63	49	7.5	29.3.
260	9	88	53	41	8.4	29.3.
330	7	86	32	29	12.0	4.4.

Table 1: Telescope Efficiencies

The main beam and aperture efficiencies, and the beam widths, were derived from Mars observations. The observations on April, 4th, were conducted at an elevation of 43 deg, i.e. near the maximum of the gain elevation curve. The

observations on March, 29th, were conducted at elevations between 29deg and 44deg. The ellipticity of the beams is better than 90% in all cases. Mars was pointlike with a diameter of 4arcsec.
The forward efficiencies in Table 1 were derived from Skydips are are averages of individual observations (cf. Table 2). All skydip observations conducted in the week before Apr, 1st, resulted in the following efficiencies:

Band	Freq (GHz)	Feff
E0	86, 98	95
E1 (with E0)	147	92
E1 (with E3)	145, 147	95
E2	210, 230	94
E2	260	88
E3	330	86

Table 2: Forward Efficiencies for EMIR bands

The analysis of the skydips was done manually. The atmospheric temperature Tatm was derived with the program ATM. The agreement between the atmospheric opacity derived from the skydips and those determined by the standard (chopper-wheel) calibration, agree very well. At present, it is not clear whether the slight 3% difference in forward efficienciers found between observations with band E1 together with E0, or together with E3, i.e. with different dichroics, is significant or not.

1.6 Errorbeam observations.

We conducted total power scans across the full moon to study the telescope error beams. The results agree with results previously obtained with the ABCD receivers, as expected.

1.7 Pointing and flux monitoring.

Pointing scans were conducted in the traditional beam switching mode, in wobbler switching mode, and in total power mode. Under very good atmospheric conditions, the total power mode produced very good results. The beam switching mode suffered from spikes, a problem which is already known from the ABCD receivers. This will be tackled, otherwise wobbler switching may be the more efficient observing mode.

2. Spectral line observations.

2.1 Synthesizers and Local Oscillators

As the four new OmniYig synthesizers for EMIR were not delivered in time, we are currently using two Anritsu synthesizers, as temporary solution. This has caused a number of problems:

- Cables need to be exchanged for many EMIR frequency setups, as only two synthesizers are available. One of the internal connectors of one of the Anritsu synthesziers is almost broken by now. A bridge has been installed, to reduce stress on the connectors.
- The PLL may lock onto wrong harmonics which are plus or minus 50MHz apart from the correct harmonic. Reducing the harmonic mixer power, relative to the number from the tuning tables, helps. At present, the operators have to check for each tuning that the correct harmonic is locked.
- The alarming system indicates several times per day an out-of-lock alarm. This occurs at the start of scans. The PLL signal at the network analyzer does not show out-of-lock situation, which may indicate that the lock is lost only for a short time, when the frequencies are slightly changed. This situation may occur with the present set of synthesizers, but should not appear for the new ones.
- The Local Oscillator of Band 4 runs out of power for frequencies above about 345GHz, and will be replaced.

2.2Spectrometers.

During commissioning, we used the 4MHz filterbank and the two auto correlator backends WILMA and VESPA, partly in parallel. The 1MHz filterbank will be commissioned asap.
A variety of VESPA setups were checked, covering the range of resolutions between 3kHz and 1.25MHz and a wide range of bandwidths. VESPA parallel mode was also checked. However, as a reminder, it is not possible to check all possible setups. A tool to validate the selected VESPA setup in ?PaKo has been implemented.

2.3Observing modes.

The following switching modes were re-commissioned: position switching (onoff), wobbler switching, and frequency switching. Beam switching was checked using the continuum backends. The on-the-fly mapping mode was re-commissioned, in combination with position switching and with frequency switching.

2.4EMIR setups.

The following EMIR setups were requested in the proposals for this summer semester and have been commissioned. The Code corresponds to the table created by S.Navarro describing possible setups of the switch box. The listed Bandwidth is the total bandwidth covered by the resulting spectra, given to about 0.5GHz accuracy.

Band(s)	Sidebands	Polar.	Bandwidth	Code
E0	1SB	H/V	8GHz	(13)
E0	2SBs	one pol.	16GHz	(14)
E0/E1	1SB	H/V	8GHz	(121)
E0/E2	1SB	H/V	8GHz	(131)
E0(8GHz)/E2	1SB	mixed	12GHz	(135)
E1	1SB	H/V	4GHz	(2)
E2	1SB	H/V	4GHz	(3)

Table 3: EMIR Frequency Setups

The following Figure shows the frequencies of the band edges and centers of the lower and upper sidebands, and the inner and outer bands. Note that the band edges and center are **not** exactly at multiples of 2GHz relative to the local oscillator. This is due to the IF distribution. The backends are centered near the band centers. VESPA is centered at 6.25 or 9.43GHz. For WILMA, the inner and outer bands have 0.1GHz overlap. The inner band runs from 4.125 to 7.845GHz. The outer band runs from 7.835 to 11.555GHz.

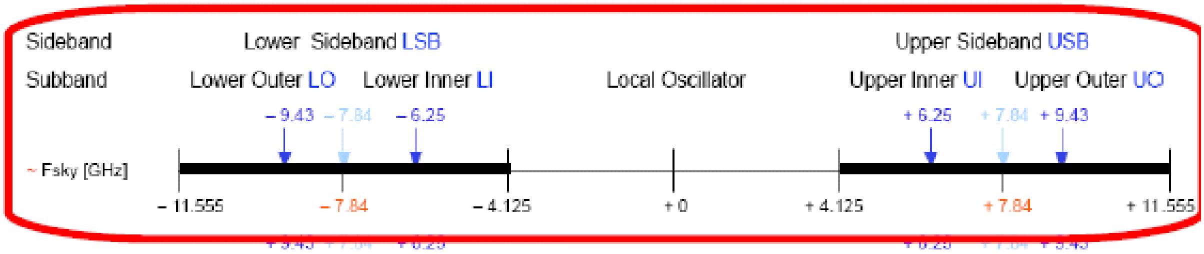

Figure 5: Frequency setup in Band 1.

2.5Band edges.

The following table lists the upper and lower center frequencies that were successfully tuned during commissioning. We put the frequencies which had been announced in the call for proposals in brackets, when different from the commissioned frequency.

Band	Lower limit	Upper limit
E0/Band 1	78 (83)	117
E1/Band 2	129.6 (129)	174
E2/Band 3	201 (200)	267
E3/Band 4	260	(360)

Table 4: Frequency ranges. All frequencies are the centers of 4GHz bands.

- Band 1: We tuned the lower outer band of the 3mm receiver to a center frequency of 78GHz, without difficulties. (In the call for proposals, 83GHz had been announced.) The receiver noise temperature rises to ~200K at the band edge near 76GHz. This setup allows to observe e.g. the N2D+(1-0) or the DNC(1-0) transitions. Trying to tune to still lower frequencies, the receiver temperature rapidly rises to several 1000K. The following image shows a spectrum of IRC+10216 taken at 78GHz.

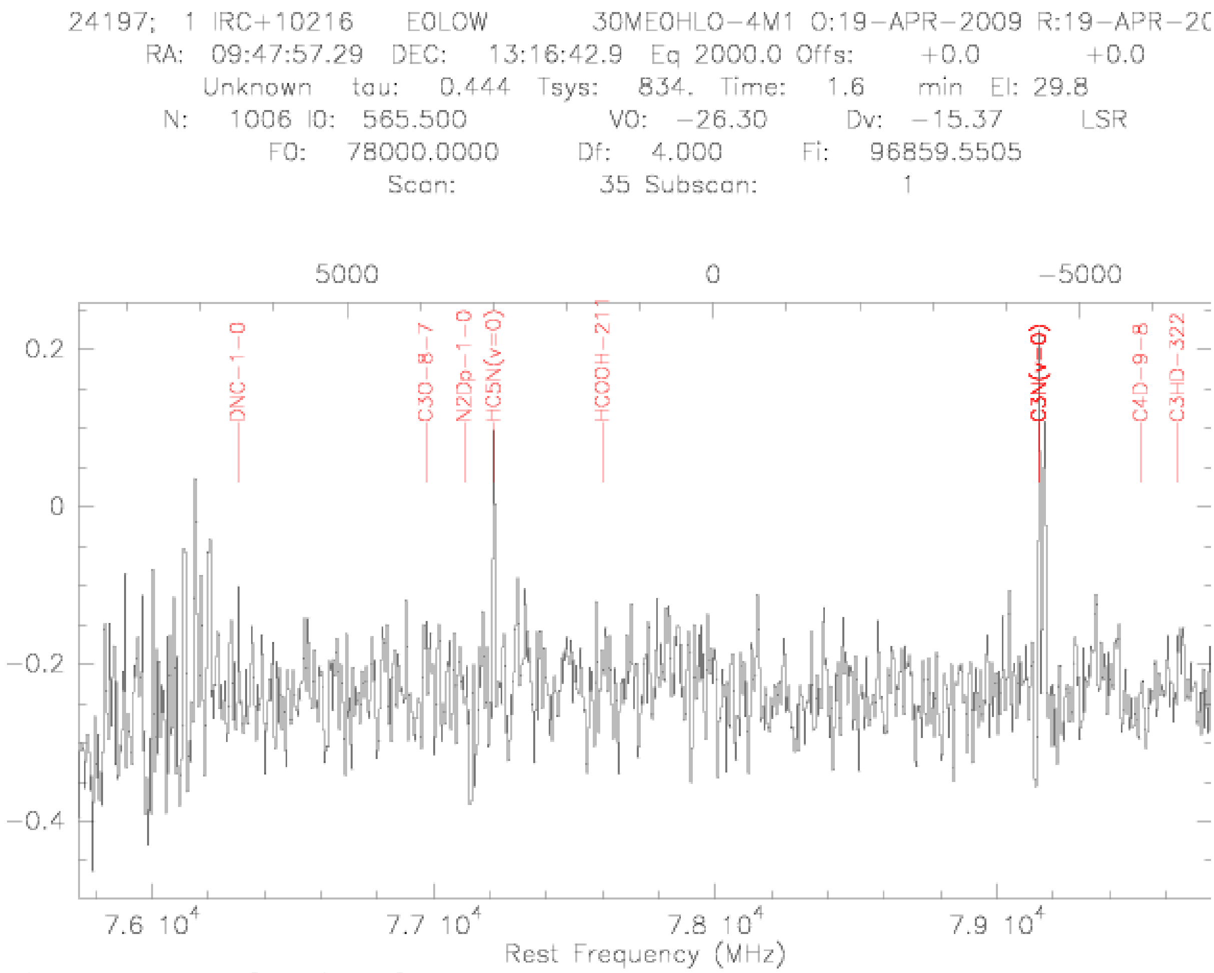

Figure 6: Lower edge of Band 1.

- E150 was tuned 129.6 GHz LI. The Trx obtained were ~ 36-32 K (Wilma & Vespa).
- The upper edge of band 4 will be commissioned later.

2.6 Standing waves.

We did not conduct a thorough analysis of standing waves with EMIR, but rather give one example here. Spectra taken on Uranus near 233GHz show standing waves, similar for both polarisations, on a baseline offsets due to the continuum of 3.9K TA*. A fft analysis indicates that the major ripple frequencies are 140, 310, 1000MHz. This corresponds to about 1m, 0.5m, and 15cm cavity length. Spectra taken on Callisto and Neptune confirm these typical ripple frequencies. More importantly, amplitude and phase stay constant over a period of more than 20minutes. (Based on an analysis contributed by Raphael Moreno, 7.5.09).

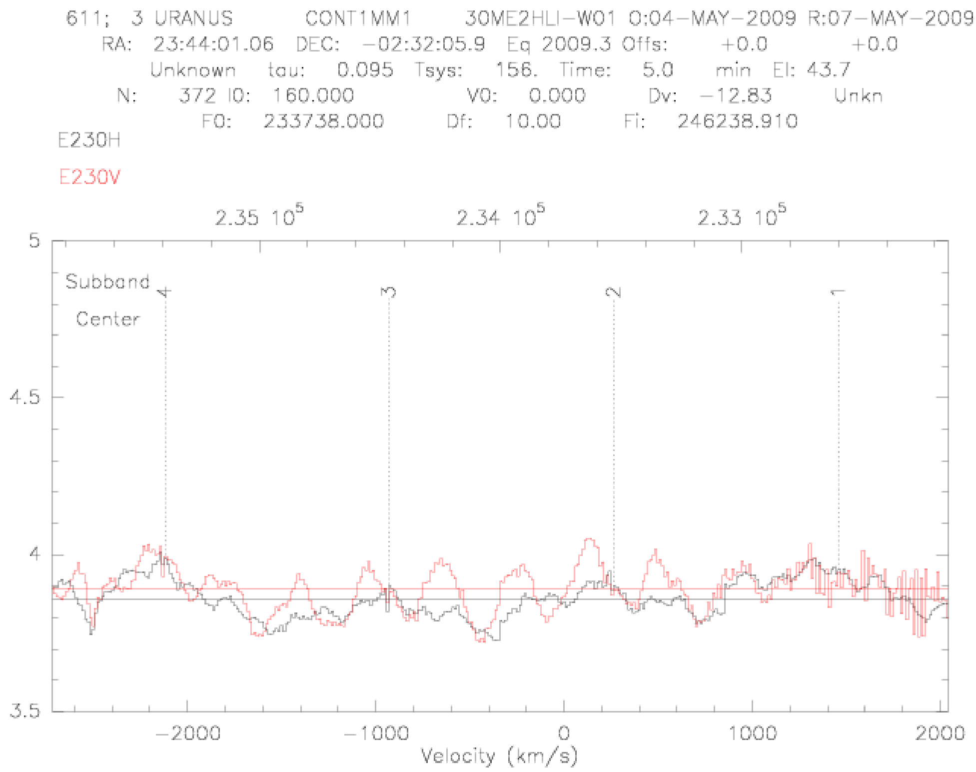

Figure 7: Uranus spectra.

2.7 Receiver gain ratios.

It was not attempted to measure systematically the gain ratios in the four bands, or even to measure the gain ratio variations over the bandpasses. Here, we rather restrict ourselves to three comments.

- In the receiver lab in Grenoble, the image gain had been measured for the 2SB mixers (bands 1 & 4). For the SSB mixers (bands 2 & 3) then gain was optimized. It is definitely better than -10dB at the center of IF, possibly worse at edges of 4GHz band.

- The default receiver gain ratio in PaKo has been set to -13dB for all receiver bands. The maximum error on the antenna temperature scale, introduced by a variation between -10dB and infinity, is 5%.
- During commissioning, the gain ratio was measured only once: The 12CO 1-0 line in IRC+101216 showed up in the lower sideband, at 102.772, reduced by a factor of 24, corresponding to a gain ratio of -13.8dB. This shows the potential of frequency surveys, like the one conducted on Ori IRc2 shown below, to measure the variation of the gain ratio over the band pass, similar to what has been done for lab spectra taken with HIFI.

2.8 Status of Band 4 commissioning.

- E3 lower band tuning was checked (260GHz). It was possible to tune it, but changing the harmonic mixer bias was needed. The Trx obtained were ~60-65K at LI band.
- Telescope efficiencies were measured at 330GHz (see above).
- The Local Oscillator lacks power above about 340GHz and will be replaced.
- The variation of aperture efficiency with elevation is the strongest in Band 4. In August/September 2009, Mars will rise to above 70deg, and will stay small, allowing to measure accurately the gain elevation curve.

2.9 Science verification.

The following figure shows a spectrum of Orion IRc2 covering 32GHz of the 3mm window. It was taken with WILMA in wobbler switched mode in two EMIR setups in 30minutes of on+off observing time. Each EMIR setup used 16GHz simultaneously, both sidebands, with one polarisation. One broken WILMA unit was later repaired. The 4MHz/8GHz Filterbank was used in parallel, but data are not shown here.

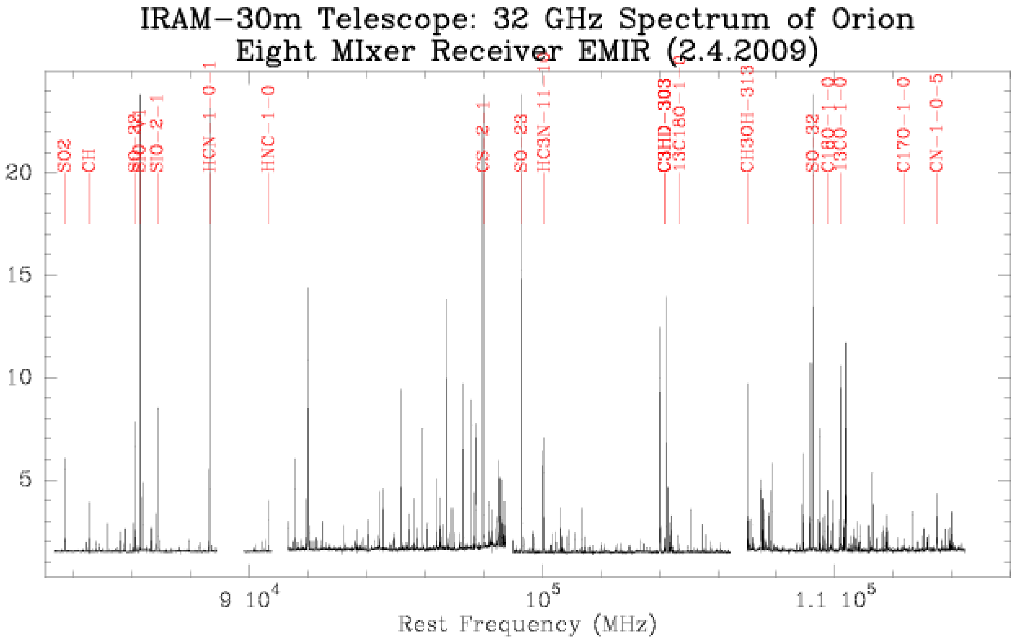

Figure 8: Spectrum of Orion IRc2.

A long 4 hour integration of the Cloverleaf, a quasar at high redshift, in the 3mm window, resulted in flat baselines with 0.4mK at 150km/s resolution. For this, we used WILMA in wobbler switching mode. The redshifted CO 3-2 line is confirmed.

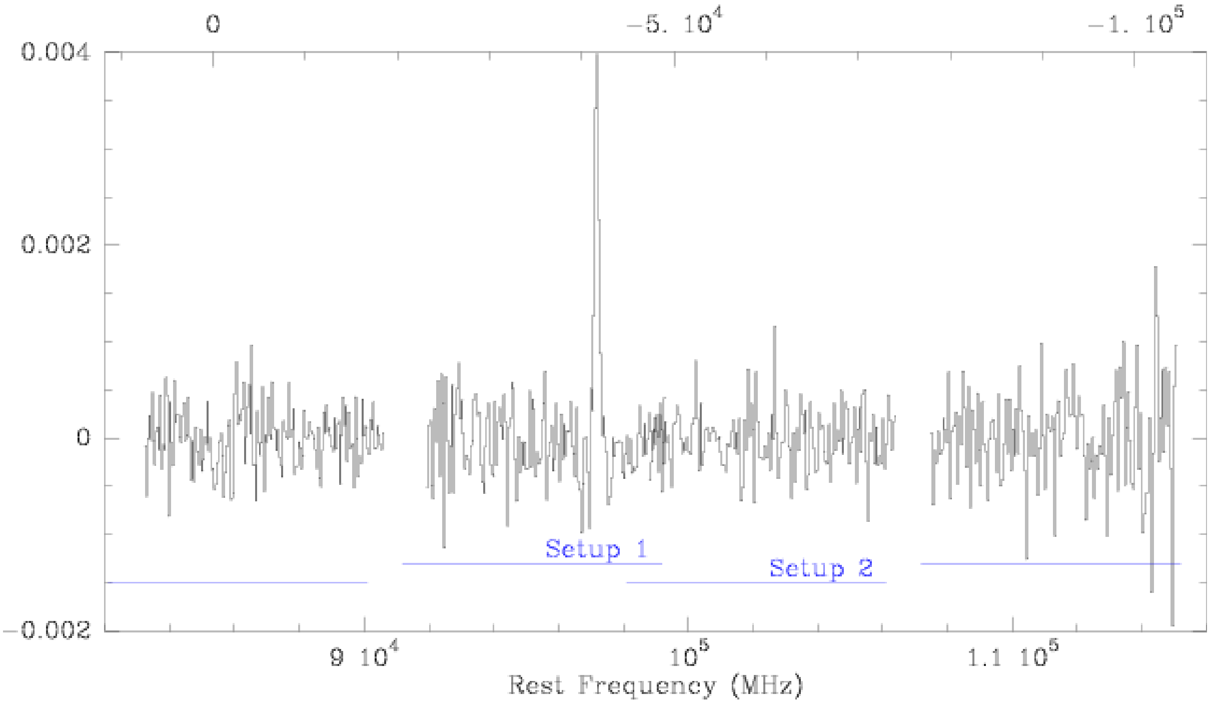

Figure 9: Spectrum of the Cloverleaf quasar.

3. Next steps

- A number of smaller items, left over from commissioning, will be addressed in the coming weeks, and are not listed here.
- In mid June 2009, four new remotely controlled synthesizers will be installed. So far we have however been working with two synthesizers in the receiver cabin, causing a number of problems. The operators have to switch cables to the synthesizers in the receiver cabin, when changing the EMIR setups. With the present synthesizers, the harmonic mixer power often need to be reduced relative to the tabulated values, to avoid locking onto a harmonic at plus or minus 50MHz. We have the suspicion that slight frequency changes cause the present synthesizers to loose lock for a brief period of time. All these problems should be solved with the new set of synthesizers.
- It is planned to commission the 1MHz/1GHz filterbank as soon as possible.
- Polarimetry with EMIR shall be commissioned in mid June 2009. VESPA will be used in cross-correlation mode, as before. Phase calibrations will be done with a polarizer in front of an external cold load.
- The band 4 Local Oscillator will be replaced.
- Installation of the four new EMIR synthesizers is planned for mid June.
- At present, NCS still uses an old atmospheric model ATM, which includes only atmospheric water and oxygen lines. Lines of e.g. Ozone, are missing. Implementation of a new model is in preparation to improve the calibration, especially in the atmospheric windows at 1mm and 0.8mm.