Commissioning of the new receiver cabin optics

V0.9.4, 29th May, 2015

H. Ungerechts, A. Sievers, C. Marka, I. Hermelo, J. Penalver, C. Thum, C. Kramer

ABSTRACT.

Here, we report on the results and status of the astronomical commissioning in the period 16-April till 28-April 2015.

The new optics was checked on the sky using EMIR under moderately good and stable weather conditions. Two pointing sessions resulted in an all-sky rms of less than $2''$. Nasmyth offsets of both EMIR beams hardly changed. FWHMs compare well with the values known from the old optics. Peak temperatures and widths measured with the Chopper compare very well with Wobbler observations, i.e. no indications of beam truncation were found for neither of the EMIR beams. Measured forward efficiencies derived from skydips are slightly lower than expected, especially at 1 mm. Secondary calibrators observed during night time are consistent with previous observations within the expected scatter, also at 1 mm. Mars was only available during day-time and at 10-40 deg from the sun. Aperture efficiencies and Jy/K conversion factors were also derived and agree within 5% with the previous values. The beam efficiencies agree within 8% with the previous values. Ceres was detected with E0/E2 and BBC after just 4 minutes of integration time, also using the new continuum observing mode onoff. Flux at 1 mm is only 12% off from the value predicted for this date. Axial and lateral focus values are in the usual range observed with the old optics. Pointing changes with z-focus, stronger than with the old optics (factor 4). From the alignment team we know that the laser spot on the subreflector performs a "dance" by ± 3 cm when doing a full sweep in elevation between 0 and 90 degrees. Polarimetry with EMIR and VESPA was successfully commissioned for point sources. Sidelobes still have to be mapped. Since the evening of 22-April, EMIR has been used again for science grade observations of regular projects, including polarimetry of point sources.

In June, we plan to observe Uranus before sun-rise, to check the gain-elevation curve. In addition, more skydip observations are planned.

HERA commissioning was attempted in the period 24-April till 28-April. However, weather improved only on 27-April, when we could finally start serious tests, which all went well (see below). The de-rotator is well aligned. Nasmyth offsets of $+4.8''/+9.9''$ have been determined after two pointing sessions. The beam efficiency at 230 GHz agrees within 5% with the expected value. On the other hand, the forward efficiency at 1 mm is 10% lower than the value obtained with the old optics. We need to repeat these skydip measurements under best conditions.

Contents

1 Commissioning

1.1 Pre-commissioning status

The optical alignment of EMIR finished on 16-April, when the astronomical commissioning started. The alignment team reported that the laser alignment went very well and that there are only few potential issues:

- It had been found that the chopper blade covers the central beam on M4 only to about the beam waist. Subsequent commissioning (see below) did however not show any indications that any of the EMIR beams are affected.

- The laser spot on the subreflector (coming from M4) is shifting or "dancing" slightly when moving in elevation. At zero degree elevation the laser was ~ 3 cm on the low-right side of the center of the scatter cone at the center of the secondary. Between 0 and ~ 30 degrees it doesn't move, then between 30 and ~ 50 and 60 degrees its moves passing at the center of the cone, then stabilizing at ~ 3 cm on the up-left side of the center of the cone. Between 60 and 85 degrees it doesn't move anymore. (SL, 22-April) With the old optics, the laser spot also showed a "dance" of a few cm. (SN, 5-May)

- The calibration tray of EMIR, which includes a mirror for E0/E1, had to be dismounted during the installation and was remounted. E0/E1 alignment was successfully checked during commissioning – see below.

- Any small variation between the inclinations of the position of the new M4 mount and the horizontal bar to which the new M3 mount is now attached, has been monitored during the past months (Fig.15). After installation of the new optics, the relative inclinations changed, but quickly stabilized at a new value.

  The jump seen in Figure 15, after installation of the new mounts, corresponds to a small deformation of the horizontal steel bar supporting the new M3. The main deformation toward the vertex means a rotation of the bar in that direction due to the new weight. About the inclination parallel to the elevation axis, it remains to be seen if the previous drift range of about $60''$ (mainly due to weather changes) still continues or now, with the extra load, it is more stabilized as by the moment seems to be the case.

  That the deformation concerns only to the inclinometer close to M3 is confirmed with the Figure of the inclinometers during the days of the installation of M3 and M4. Those days the antenna stayed at the stow position, which made it possible to see the jump. During longer periods of time, when the antenna is moving in azimuth, the amplitude of the measured inclination is bigger due to the inclination of the antenna azimuth axis.

1.2 EMIR

During commissioning the following EMIR band combinations were observed: E0/E1, E0/E2, E1/E3. All observations were conducted with BBC and partially also with NBC. Observations were done on primary calibrators Mars, Uranus, Neptune (which unfortunately are only available during the morning daylight hours), on secondary calibrators K3-50A, NGC7027, NGC7538, W3OH (which are available during night-time), and on quasars. Spectral line observations were deemed unnecessary and were not done.

Weather conditions for 17-April till 19-April: 225 GHz taumeter zenith opacities were good: between 0.15 and 0.3. Atmosphere became instable at about noon and then went stable again at about 6-8pm. Wind sometimes increased to 10 m/s, but not more.

1.2.1 Continuum observing modes.

The chopper throw was measured and found to be $142''$. This is a bit smaller than the most recent value of the old optics. The difference was expected as the distance between chopper blade and M4 had been about 8 cm with the old optics before this work, and now it is 6 cm. EMIR beams are separated horizontally by about 65 mm on M4 (SN). When using the chopper, `mira` only identified only few (1-2) spikes per subscan, as before.

Continuum sources were observed with different observing modes (point/swbeam, point/swwobbler, point/total, onoff/swwob) to check for any systematic effects, in particular when comparing with beam switched observations. Beam switching compares very well with wobbler switched observations. Peak temperatures and FWHMs are very similar, over a wide range of elevations (Fig. 1).

1.2.2 Nasmyth offsets.

Nasmyth offsets of the old optics were used, finding no indications that they need to be revised (within about $1''$ accuracy over 30 degrees in elevation). Figure 2 shows the variation of pointing offsets for both EMIR beams, E0 and E1, when changing the elevation and azimuth. Pointing stays constant to withing better than $1''$.

1.2.3 Pointing sessions.

On 17-April, a pointing session was conducted during the second half of the night, observing 42 sources. Three parameters were fitted (Table 1), improving the pointing scatter (Fig. 3). The final pointing rms is exzellent: $1.6''$.

The above model was implemented, and, on 23-April, another pointing session was run, which confirmed an excellent overall pointing accuracy (Table 1).

1.2.4 Focus

z-Focus values. Fitted z-Focus values were lying in the usual range, between -2.0 and -2.6 mm.

Table 1: Fitted pointing constants from EMIR E0 observations.

1st run, 17-April, 42 observed positions rms=$3.5''$ before fit, rms=$2.2''$ after fit			
P2:	-6.36"	± 0.33"	
P8:	-9.34"	± 0.76"	
P9:	$+2.26$"	± 0.80"	
2nd run, 22-April, 33 observed positions rms= $1.66''$ before and after the fit			
P2:	-3.04"	± 0.28"	(azimuth offset)
P7:	$+1.55$"	± 0.28"	(elevation offset)

Change of pointing with z-focus. To check the alignment of M1, M2, M3, the Mars pointing was monitored when moving the z-focus by 5 mm, between about -5 and 0 mm. These observations are compared to similar observations done with the old optics. **The pointing offsets are systematically shifting when changing the z-focus by 5mm.** The gradient changes with elevation. With the old optics this gradient was less than it is with the new optics (for similar elevation). With the old optics the gradient was -0.2"/mm in Az and in El at $60°$ elevation, with the new optics the gradient is $+1$"/mm in Az and in El at $53°$ elevation. At $36°$ elevation, the new optics shows $+0.5$"/mm in Az and in El. Gradients show-up in both EMIR beams. There is quite some scatter on these measurements, but the gradients are clearly not zero (Table 2).

Table 2: Variation of pointing when changing z-focus. We use here the total pointing offset in Azimuth plus Elevation. The residual rms in Az/El is given in brackets.

Elevation deg	Frontend	Az-Drift $''$/mm	El-Drift $''$/mm	Date
60	E0	-0.2	-0.2	30-Mar, Old optics ($0.3''/0.5''$)
53	E0	$+0.9$	1.0	20-Apr, New optics ($1.3''/1.7''$)
38	E0	$+0.6$	$+0.5$	23-Apr, New optics ($0.7''/1.1''$)
37	E0	$+0.7$	$+0.3$	20-Apr, New optics ($0.7''/0.6''$)
27	E1	$+2.0$	$+0.1$	23-Apr, New optics ($0.8''/0.8''$)

Lateral focus offsets. Moving the lateral focus in x or y by ± 2.5 mm, leads to a significant drop of flux, roughly 20% at 1mm, which allows to determine the lateral focus. A series of lateral focus observations were conducted on Mars using E0/E2 on 20-April. Observations were conducted at 28 and 47 deg elevation and for each elevation observations were repeated three times. The focus length was ± 2.5 mm, i.e. much more than the default of ± 1 mm. This resulted in reproducible focus values (Table 3, Fig. 4).

As figure 4 shows, **E2 shows sometimes markedly different lateral focus values compared to E0.** Offsets are 0.4 to 0.6 mm ! But for E2 no significant deviations from lateral focus values of x/y=0/0 were found. It was therefore decided not to set different values, even though from time to time coma-lobes appear next to the 1mm elevation beam (at about 1/20 of the peak intensity) (Fig. 9). Such behaviour has been known for long.

Uranus lateral focus scans were done with the old optics on 9-Dec-2013, with eight good lateral focus scans on Uranus, scans 250 to 257, four scans in each direction, in the elevation range 42.6 to 46.5 deg. With small differences, a similar offset to the current situation with the new optics is found between E0 and E2:

```
focusX(E0) - focusX(E2) = -0.16 +- 0.06 mm
focusY(E0) - focusY(E2) = +0.38 +- 0.06 mm
```

Table 3: Lateral focus observations on 20-April.

Rx Band	Elev. deg	focus X mm	focus Y mm
E0	28	-0.42 ± 0.12	-0.04 ± 0.11
E0	47	-0.37 ± 0.21	$+0.09 \pm 0.10$
E2	28	$+0.17 \pm 0.15$	0.00 ± 0.14
E2	47	$+0.13 \pm 0.19$	-0.54 ± 0.10

For about a day, on 18 to 19-April, the lateral focus had been set to $-0.2/+0.4$mm, which did however not have a noticable effect on the measured temperatures or widths.

1.2.5 Flux monitoring sessions.

Several flux monitoring sessions were conducted between 8pm and 2am. SwWobbler observing mode was used.

On 18-April, E0/E1 was used, pointing corrections varied between $-7''$ and $-4''$ in Azimuth and $-16''$ and $-7''$ in Elevation. Agreement between polarisations and bands was found to be better than $1.5''$. Focus in z varied between -2.0 and -2.6 mm. The agreement of polarisations and bands was found to be better than 0.3 mm.

1.2.6 Beam shapes

For E0, E1, and E2 the fitted FWHMs compare very well (within few percent) with the predicted half power beamwidths[1] as seen in Table 4 and in the Figures. Transient weak coma lobes were sometimes visible in Elevation scans (Fig. 9). See also section 1.2.4.

[1]With the old optics, we had found that the relation HPBW=2460/Freq, with HPBW in arcsec and Freq in GHz, fits well the observed HPBWs (see 30m wiki).

1.2.7 Beam efficiencies.

To derive main beam efficiencies, we followed exactly the same procedure as used previously for planetary measurements with the old optics: source fluxes S and sizes θ_s were taken from `astro/planet` for the observing frequency and date. The measured FWHM was de-convolved to find the observed HPBW (HPBW=$\sqrt{\mathrm{FWHM}^2 - \ln 2/2\theta_s^2}$) and this was compared to the best fit result: HPBW/arcsec = 2460/ν/GHz, which had been obtained with the old optics. And we used the following formulae [10] for the aperture efficiency $A_{\mathrm{eff}} = 3.905K(F_{\mathrm{eff}}T^*_{\mathrm{A,pk}})/S$, with the size correction factor $K = x^2/(1-\exp(-x^2))$ and $x = \sqrt{\ln 2}\,(\theta_s/\mathrm{HPBW})$, the flux conversion factor on the T^*_A scale JYK= $3.905F_{\mathrm{eff}}/A_{\mathrm{eff}}$. Here, the forward efficiency is the one set by default in the drive program ! The main beam efficiency is $B_{\mathrm{eff}} = 0.8899(\mathrm{HPBW}\ D/\lambda)^2 A_{\mathrm{eff}}$, with the HPBW in radian and the telescope diameter D and the observing wavelength λ in meters, assuming here HPBW= $1.2\lambda/D$, i.e. $B_{\mathrm{eff}} = 1.28\,A_{\mathrm{eff}}$. [2]

Mars only has a diameter at present of $3.9''$. Uranus and Neptune are still smaller on the sky. These planets were only visible during the morning hours after 9am. Furthermore, Mars and Uranus were within only $\sim$ 10 deg of the sun. For the 1 mm data, we selected scans of excellent pointing ($< 1''$) near the optimum elevation of the telescope of 50 degrees, i.e. near the peak of the gain-elevation curve.

Table 4 (cf. Fig. 5) lists the derived beam efficiencies which agree within 8% with the previous values.

Low beam efficiencies at 1 mm could in principle be explained by distortions of the main dish caused by solar irradiation of the telescope. J. Penalver (Fig. 8) has reported a drop of Uranus peak temperatures at 1 mm during sunrise, by as much as 30%, while the 3 mm temperatures stay unaffected, from observations on 6-Jul-2010. As long as the beam widths are not affected, this drop directly translates into a corresponding drop of beam efficiencies. Similar findings at 1 mm were reported by A. Greve in an older report of 1996 [8] from observations of Mars (at $4''$ diameter) during sunrise.

1.2.8 Secondary calibrators.

Secondary calibrators. W3OH, K3-50A, NGC 7027, and NGC 7538 were observed under good night time conditions. z-Focus and pointing were carefully checked and corrected. During regular flux monitoring, SwWobbler was used. The agreement is good between the observed peak temperatures and the temperatures known from the flux monitoring sessions using the old optics (Table 5). **Only NGC 7538 deviates a bit.**

Asteroids. The asteroid and dwarf planet Ceres was observed and well detected at 3 and 1 mm on 20-April-2015 (Table 6, Fig. 7). To our knowledge this is the first detection with heterodyne instruments at the 30m. Pointing was initially off by $48''$ in Azimuth indicating that the used **JPL ephemerides were imperfect**. The observations were carried out under regular atmospheric conditions (pwv 5 mm) and at low elevations (30 deg).

Vesta is predicted to be just a factor 2 weaker, but could not be detected. Ephemerides may be more off.

[2] When using p.59, Eq.4.13, Eq.5.33 of [12], we find that the observed relation, HPBW=2460/nu with HPBW in arcsec and nu in GHz, is consistent with an edge taper of -16.2 dB, HPBW=1.20(λ/D) in radian, and $B_{\mathrm{eff}} = 1.28\,A_{\mathrm{eff}}$.

Table 4: Main beam efficiencies. Measured peak temperature and width (FWHM). To derive beam efficiencies, the HPBW observed with the old optics are used, as they had been measured under excellent conditions. To go to the T'_A scale, we use the forward efficiency which are at present still set in `pako`, and which are the best forward efficiencies measured with the old optics. Derived forward, aperture, and beam efficiencies are listed, together with Jy/K conversion factor, and the best known value for the beam efficiency with the old optics. The aperture and beam efficiencies agree better than 6% with the values obtained with the old optics.

Freq.	$T^*_{A,pk}$	FWHM obs.	HPBW deriv.	HPBW old	$F_{\rm eff}$	$A_{\rm eff}$	Conv.	$B_{\rm eff}$	Source
GHz	K	$''$	$''$	$''$	%	%	Jy/K	%	
84.5	0.4	29.4	29.4	29.1	95	66	5.62 (-5%)	84 ($+4$%)	Neptune
132.7	4.5	18.7	18.6	18.5	93	54	6.76 ($+5$%)	69 (-6%)	Mars
227.0	10.9	10.4	10.2	10.8	92	46	7.78 (-3%)	58 (-2%)	Mars

1.2.9 Skydips.

Skydips were done regularly to check for any blockage and to derive forward efficiencies. Any blockage may show-up as deviation of observed temperatures at particular elevations. Nothing of this was seen in any of the skydips. Table 7 lists the observed forward efficiencies. Tip scans are now logged in TAPAS.

Skydips were done during day and night, showing no significant differences, **but values are slightly lower than expected.**

1.2.10 Maps.

EMIR Maps of $2' \times 2'$ were taken in different observing modes (Fig. 10), but **cannot yet be reduced in** `mira`.

1.2.11 Polarimetry.

Polarimetry calibration is working, the mirror and the grid move correctly. The mirror for polarimetry in front of EMIR had to be adjusted on 23-April. This adjustment improved the illumination of the grid and the temperatures of the correlated power was measured to be ~ 100 K for E2, and also for the larger beam of E0, i.e. at the expected value. The instrumental polarisation was measured and Mars and found to lie at the expected value of about 1%. Beam maps were conducted on 24-April. E0 beams seems OK, E2 maps are yet missing. The Crab nebula was mapped on 29-April by S. Monlina and I. Agudo under low opacity and stable atmospheric conditions as part of the MAPI 266-10 program.

Table 5: Peak temperatures of secondary calibrators observed during flux monitoring sessions at night time. Values are compared to the standard values which had been observed with the old optics. Lateral focus were at 0/0 on 18-April, and $-0.2/+0.4$ on 19-April. Standard values for W3OH, K3-50A, NGC7538, NGC7027 are taken from mails of H. Ungerechts of 19/27-April. Values in brackets were taken under non-optimum conditions (e.g. not focussed at 229 GHz) The standard values for 86 GHz are consistent with the values compiled in [9].

Frequency GHz	Standard Old Optics T_A^* mK	New New Optics T_A^* mK	Comments on new values
	W3OH		
86	640$\pm\sim 5$%	$610-660$	18/19 April 2015
142	670$\pm\sim 6$%	~ 600	18 April 2015
229	[720$\pm\sim 13$%]	$700-770$	18/19 April 2015
	K3-50A		
82	1070$\pm\sim 4$%	1060 ± 10	18/19 April 2015, IH 22.4.
142	950$\pm\sim 7$%		
229	[760$\pm\sim 9$%]		
	NGC 7538		
82	410$\pm\sim 4$%	360$\pm$10	19/23 April 2015, low value !?
142	510$\pm\sim 7$%	450$\pm$10	19/23 April 2015, low value !?
229	[550$\pm\sim 19$%]	670$\pm$10	19/23 April 2015, high value !?
	NGC 7027		
82	810$\pm\sim 3$%	750 ± 20	18/20 April 2015, IH 22.4.
142	630$\pm\sim 7$%		
229	[400$\pm\sim 13$%]	420 ± 30	18/20 April 2015, IH 22.4.

Table 6: Peak temperature of Ceres measured in onoff/swwobbler mode with 4 subscans of 30 sec each. Lateral focus was set to x/y=-0.2/0.4 mm, which is expected to not cause any differences compared to observations at 0/0 mm. Fluxes were derived from the Jy/K conversion factors measured on Mars and Neptune with the new optics (see above). The modelled fluxes are based on values obtained at higher frequencies with Herschel and the models of T. Mueller [11]. Fluxes agree within 20%.

Frequency GHz	$T^*_{\rm A,pk}$ observed mK	Flux derived mJy	Flux model mJy	Difference
84.5	24	135	160	-19%
227.0	122	949	840	$+12$%

Table 7: Forward efficiencies from Skydips done during day and night time under good, stable weather conditions with moderate opacities (18-19 April). **All forward efficiencies are slightly lower than expected. The largest drop of 6% is observed for E2.**

Frontend	Frequency Range GHz	F_{eff} New Optics	F_{eff} Old Optics	Change
E0	$83-85$	$94.2 \pm 0.9\%$	95%	(-1%)
E1	134	$91.4 \pm 0.3\%$	93%	(-2%)
E2	$227-229$	$86.7 \pm 0.7\%$	92%	(-6%)

1.3 HERA

HERA commissioning started on 24./25. April under instable weather conditions, which improved only on 27-April, when we had excellent weather conditions, albeit with the de-icing just switched-off, the automatic hygrometer not working. In addition, it was noticed in the morning (between scans 53 and 59) that the styrofoam vertex window was broken, with the upper half still in place. The remaining parts were then removed.

1.3.1 Pointing, focus, and observing modes

Pointing with swwobbler on Mars using the central beam worked well. For swbeam, the central pixel of HERA-1 shows the known spikes when using the NBC continuum backend and HERA-2 always showed a strong ripple. Peak temperatures measured with HERA-1 were lowered relative to those measured with HERA-2. However, pointing with swbeam was almost exactly the same as for swwob. The Chopper can therefore be used for pointing and focus tests.

A systematic offset between E230 and HERA pointings was observed (of the order $13''$, i.e. with a blind pointing starting at offset 0/0 even 1K sources may not be found). A short pointing session was done on 28-April, observing 16 positions in the elevation range 20 to 60 degrees resulting in new Nasmyth constants (Fig. 11):

```
dP10: +3.20" +-0.47" (horizontal Nasmyth offset)
dP11: +13.28" +-0.47" (vertical Nasmyth offset)
```

The rms of the observed values is $3.24''$. After the fit this improves to $1.97''$. Fitting other pointing constants does not improve the fit. This is expected, as the only very recently implemented EMIR pointing model is being used.

Based on the new pointing constants, a second HERA1 pointing session was conducted on 14-May with 25 observed positions. The rms of the observed positions is $1.83''$ and the rms of the fitted values $1.5''$. The following relative Nasmyth offsets were fitted:

```
dP10 = +1.55" +- 0.82" (hor. Nasmyth offset)
dP11 = -3.40" +- 0.89" (ver. Nasmyth offset)
```

The full HERA1 Nasmyth corrections to be implemented are then:

```
dP10 = +3.20" + 1.55" = +4.75" (hor. Nasmyth offset)
dP11 = +13.28" - 3.40" = +9.88" (ver. Nasmyth offset)
```

Focus. Focus values of HERA were normal, and ranged between -1.8 and -2.5 mm. We saw no coma sidelobes.

Outer pixels with Chopper and Wobbler. Pointings were done not only on the central pixel (#5) but also on one of the lower pixels (#4) and one of the upper pixels (#6), under good conditions ($\tau = 0.2 - 0.3$) on Neptune on 28-April. The maximum pointing errors were $\sim 1''$ in Az/El, showing that the de-rotator

angle is what it is commanded to be (0 deg in this case). The peak temperatures agreed when comparing Chopper and Wobbler observations, indicating that the Chopper still works fine, even for the lower outer pixels (Table 8).

Table 8: Pointing on Neptune with 3 pixels of HERA-1. Pointing corrections are consistent between pixels and observing modes. Peak temperatures and widths show no significant differences between swbeam and swwob. (1) Half of the difference between extrema.

		d(Az) $''$	d(El) $''$	Tpeak K	FWHM $''$	Comments
pix 5	swwob	11.4	10.2	1.33	12.3	
	swbeam	10.7	9.8	1.35	9.9	
pix 4	swwob	12.0	8.3	1.18	12.1	
	swbeam	10.9	9.0	1.25	11.4	
pix 6	swwob	12.4	9.0	1.27	10.9	
	swbeam	11.7	9.0	1.25	10.2	
		± 1.1	1.5	0.16	2.2	(1)

Alignment of both polarisations Although not part of the commissioning, we checked the relative alignment of both polarisations, and found that they agree to within better than $2''$ (Table 9), consistent with the HERA commissioning report of 2006 which gives an alignment better than $1.2''$.

Table 9: Alignment of both polarisations.

date	source	#scans	d2(Az)-d1(Az)	d2(El)-d1(El)	rms(dAz)	rms(El)
24.4.	Mars	20	0.2 ± 0.7	-0.1 ± 1.5	1.3	1.1
27.4.	Mars	16	0.9 ± 0.7	-0.6 ± 0.8	2.5	1.9

1.3.2 Telescope efficiencies

Forward efficiencies On 27-April, we did skydips under excellent water vapor conditions, without vertex styrofoam membrane in place. The observed antenna temperature curves for all 9 pixels of HERA-1 show no indications of any beam blockage. **The fitted forward efficiency at 230 GHz is 83%, still lower than the EMIR value of 87%, which is already lower than the expected, old value of 92%.**

Beam efficiencies On 27-April, Mars observations at 230 GHz near the optimum elevation (at $45.8°$) yield a peak temperature of 10.35 ± 0.4 K and a width of $11.5 \pm 0.7''$ (averaging both polarisations), giving a deconvolved beam size of HPBW = $11.3''$, which agrees well with the value from the commissioning report

of 2006 of $11.7''$ [4]. The derived aperture efficiency is 45%. Using the observed HPBW, the beam efficiency is 62%, agreeing very well with the previous value of 59%. On the other hand, if we use the scaling relation $B_{\rm eff} = 1.28\, A_{\rm eff}$ (see above), i.e. if we assume a HPBW of $10.7''$, the beam efficiency is 57%, also agreeing very well with the old value.

Taking the beam map in swtotal from 27-April, a fit to the map with all pixels summed up to one beam gives: HERA-1: $T = 9.65 \pm 0.07$ K, FWHM$= 11.4 \pm 0.2''$, i.e. HPBW=$11.2''$, $A_{\rm eff} = 0.4$, $B_{\rm eff} = 0.56$ (using the observed HPBW), again consistent within 5% with the old value.

1.3.3 De-rotator

When rotating the de-rotator to positions between -80 and $+80$ degrees in steps of 20 degrees, the pointing stays stable with an rms of $\pm 0.8''$, as measured on 27-April under excellent weather conditions (Fig. 12).

1.3.4 Beam maps

Maps of $2' \times 2'$ were done on Mars in `swtotal` and `swwobbler`. These maps can now be reduced thanks to new `mira` and `class` reduction routines, which were developed by S. Bardeau, A. Sievers, and C. Marka. Figures 13,14 give an example taken on 27-April under excellent weather conditions, albeit with the above mentioned caveats. The Gaussian fits to the single pixels of HERA-1 and 2 are on a 24" grid (for pixel 5 put on 0/0) within a maximum deviation 1.1".

1.4 Figures

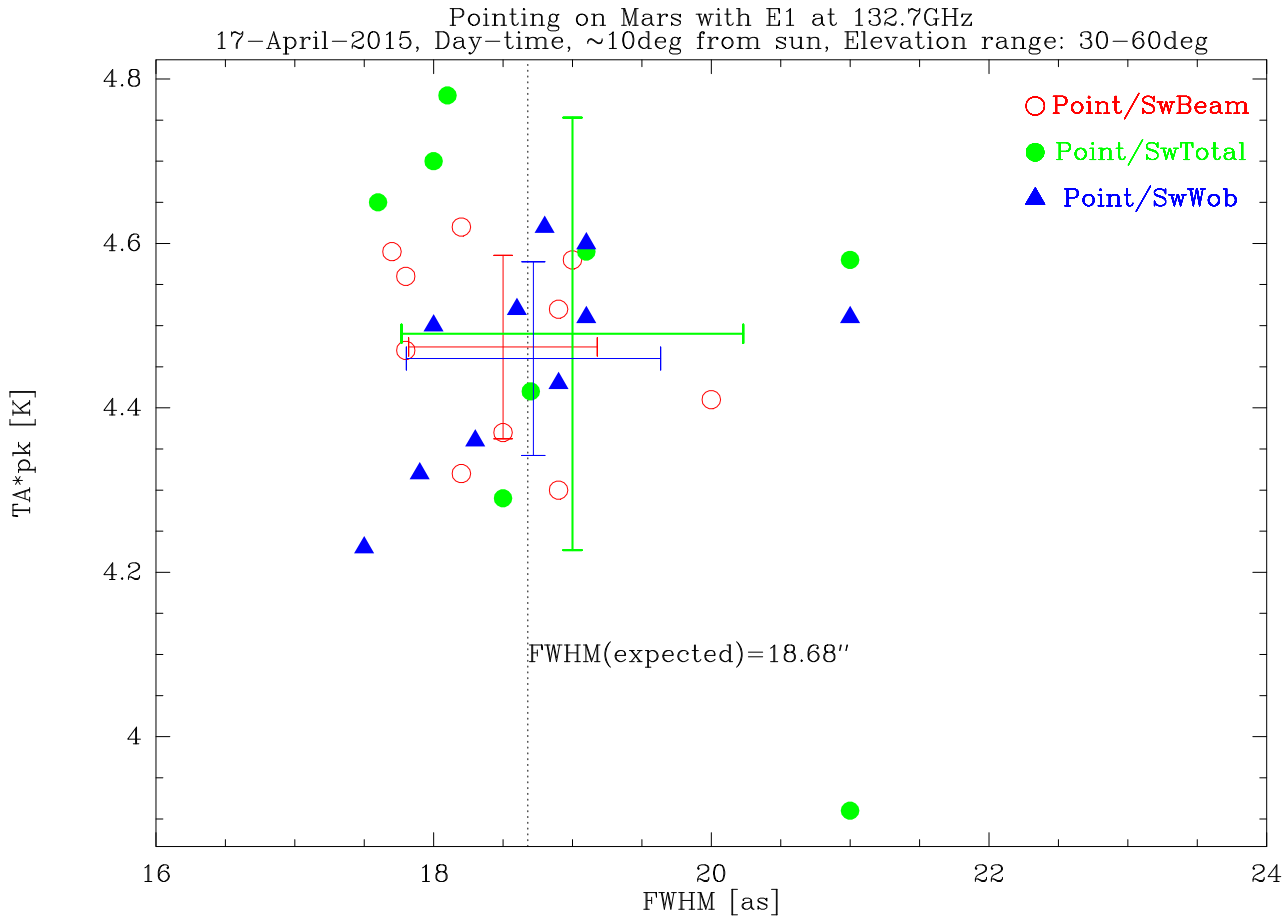

Figure 1: E150 Mars observations with different observing modes. These observations were done on 17-April, using lateral focus offsets 0/0. Average peak temperatures and widths for the different observing modes agree well. Also the measured widths agree well with the HPBW formulae (HPBW=2460/Freq) derived with the old optics.

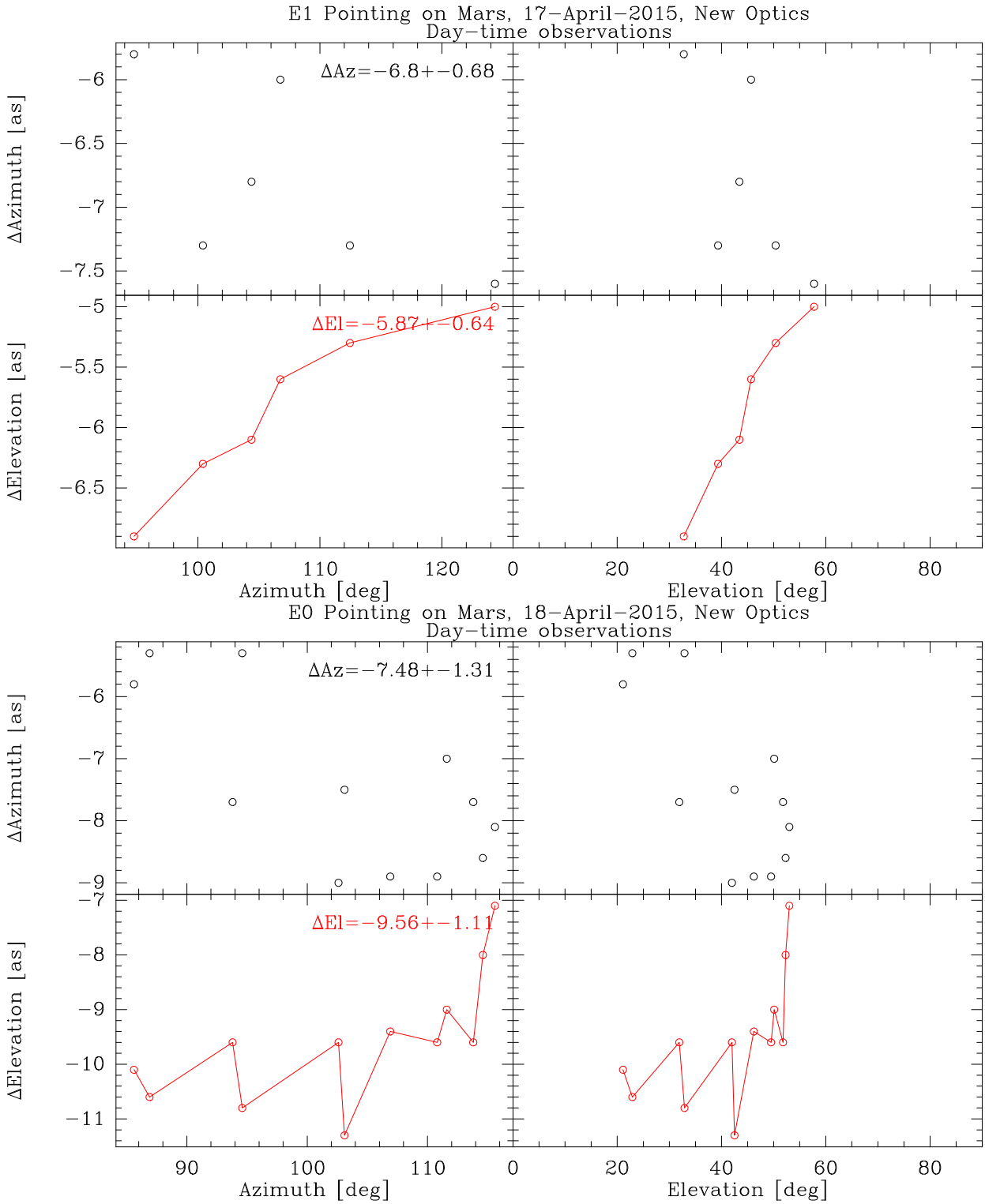

Figure 2: Variation of pointing offsets with Azimuth and Elevation. **Upper:** E1, **Lower:** E0. **Some systematic variations are visible, but at a low level.**

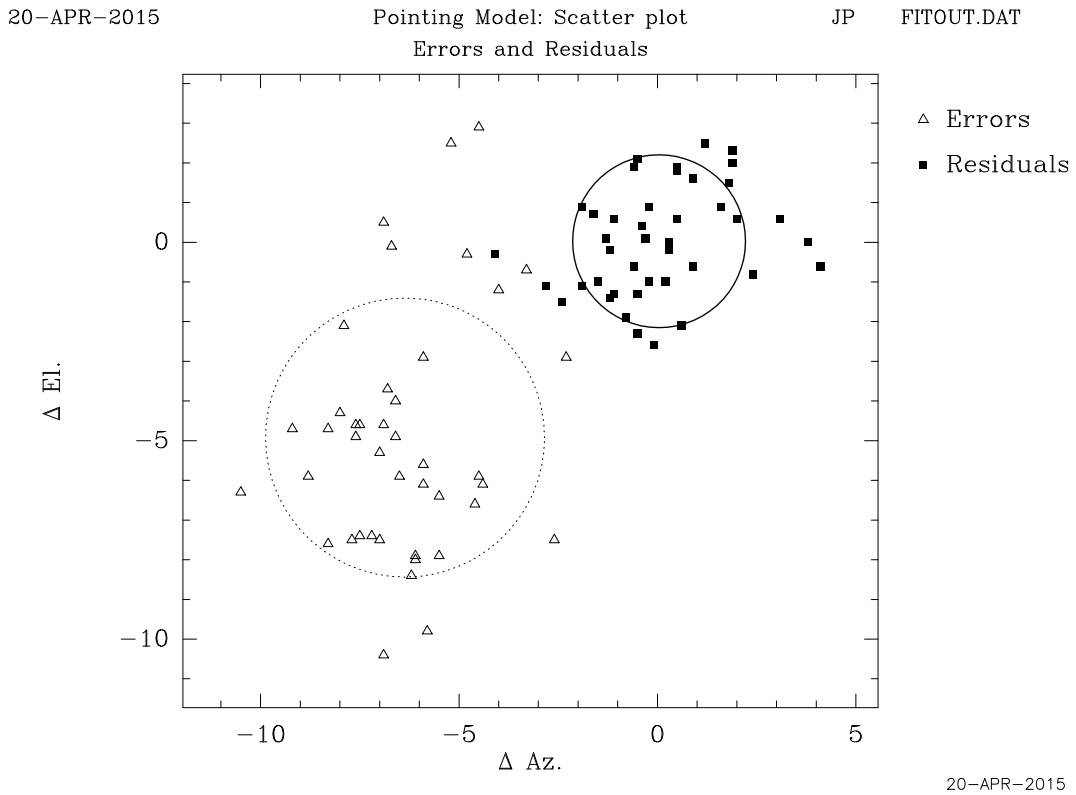

Figure 3: Pointing model: EMIR observations and fit on data taken on 17-April.

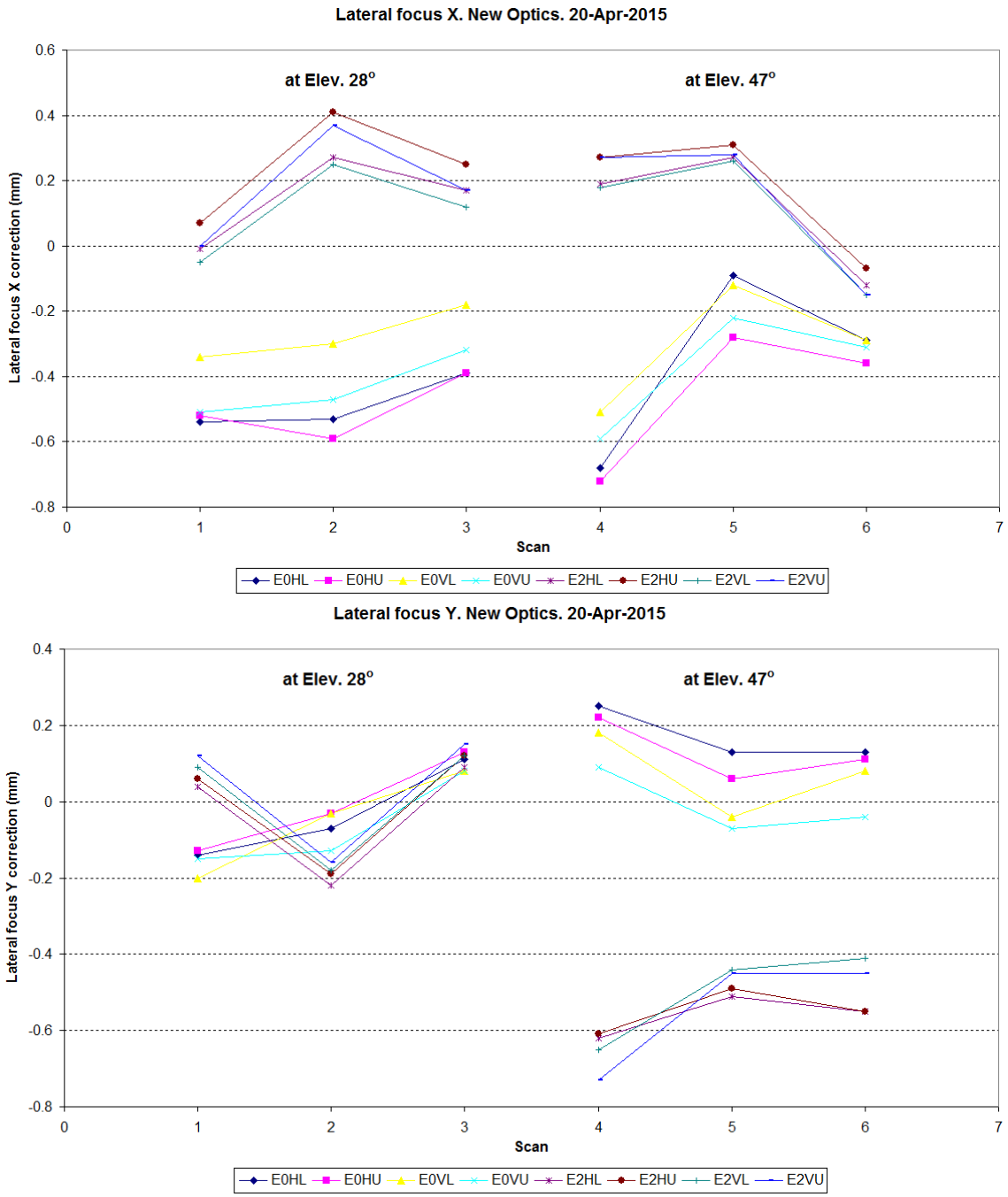

Figure 4: Lateral focus observations on Mars on 20-April.

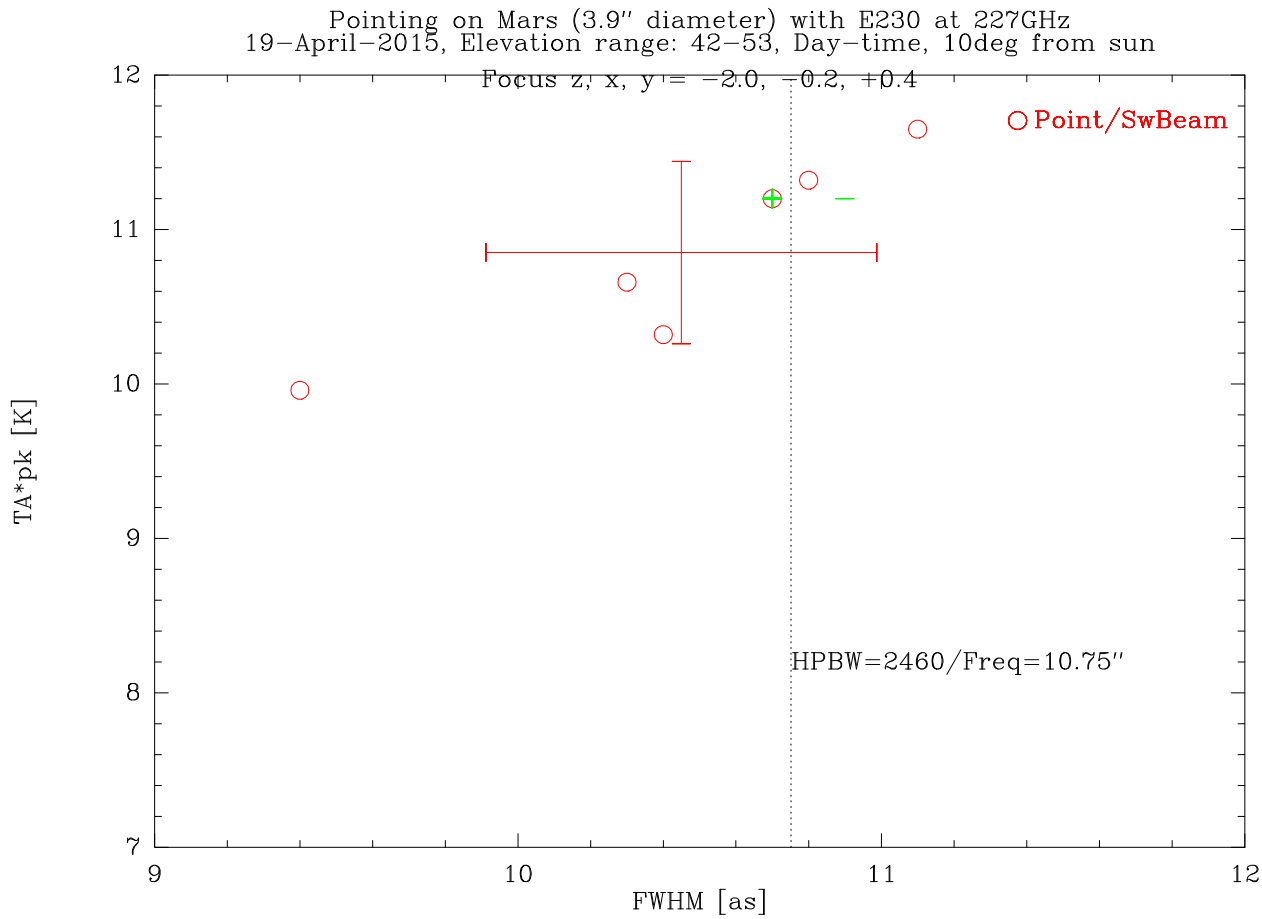

Figure 5: Mars observations at 1 mm on 19-April with lateral focus set to $-0.2/+0.4$ mm in x/y.

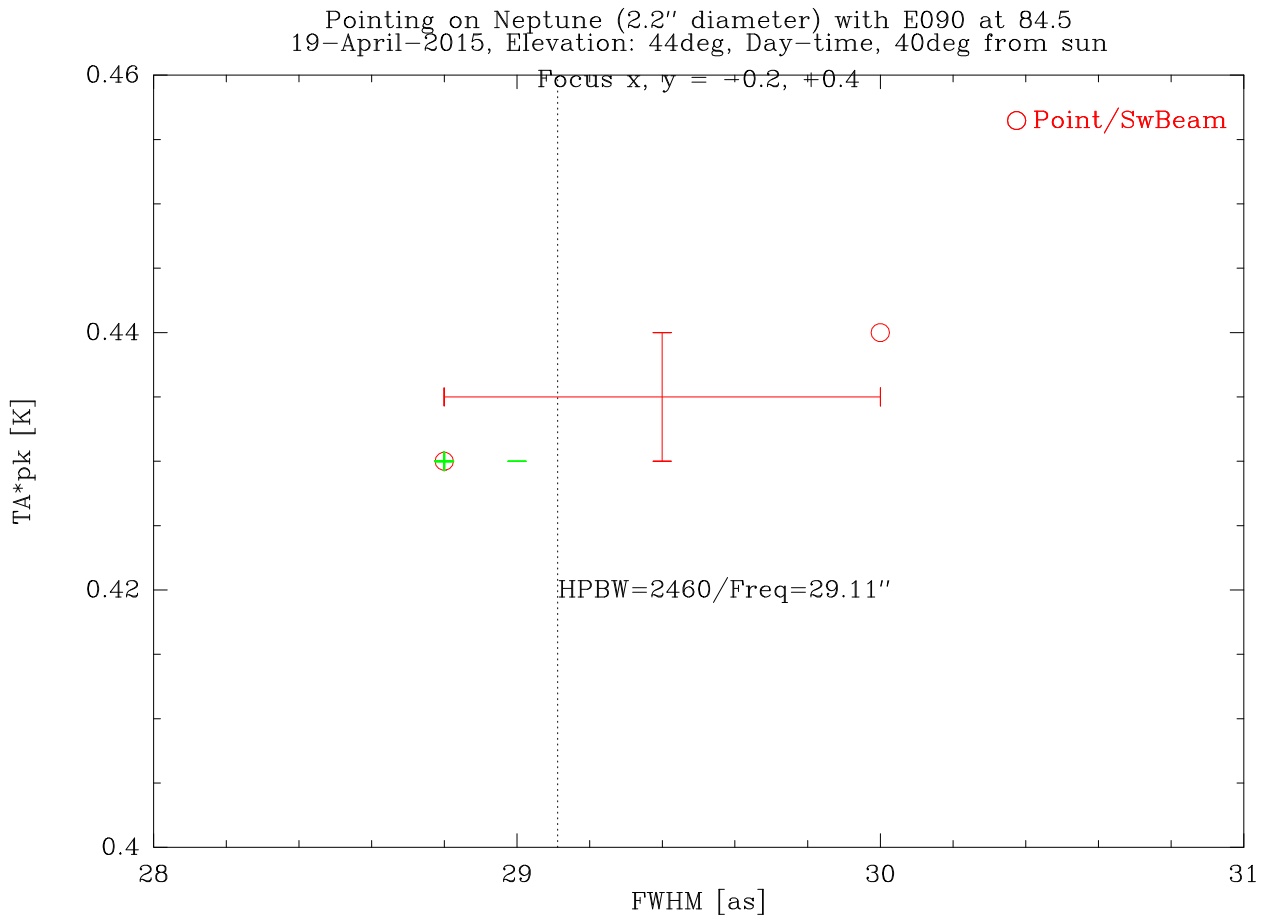

Figure 6: Neptune observation at 3 mm on 19-April with lateral focus set to $-0.2/+0.4$ mm in x/y.

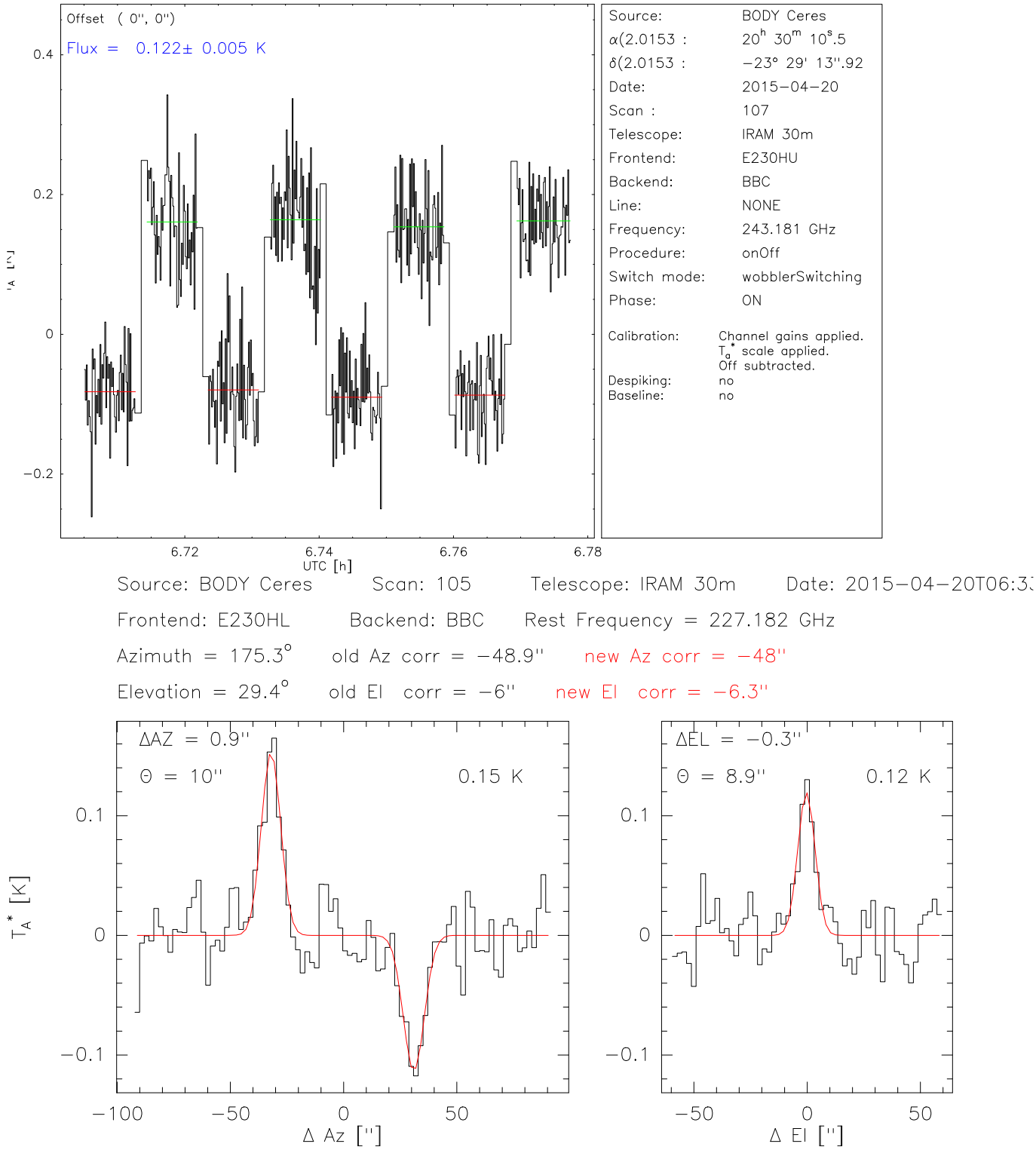

Figure 7: Ceres observations at 1 mm (20-April, x/y-focus=−0.2/0.4. **Above:** OnOff/SwWobbler observations. **Below:** SwWobbler observations. **The negative wobbler beam shows less intensity than the positive beam in this scan, indicating some perturbation during the scan, possibly by the weather. This feature is however usually not seen.**

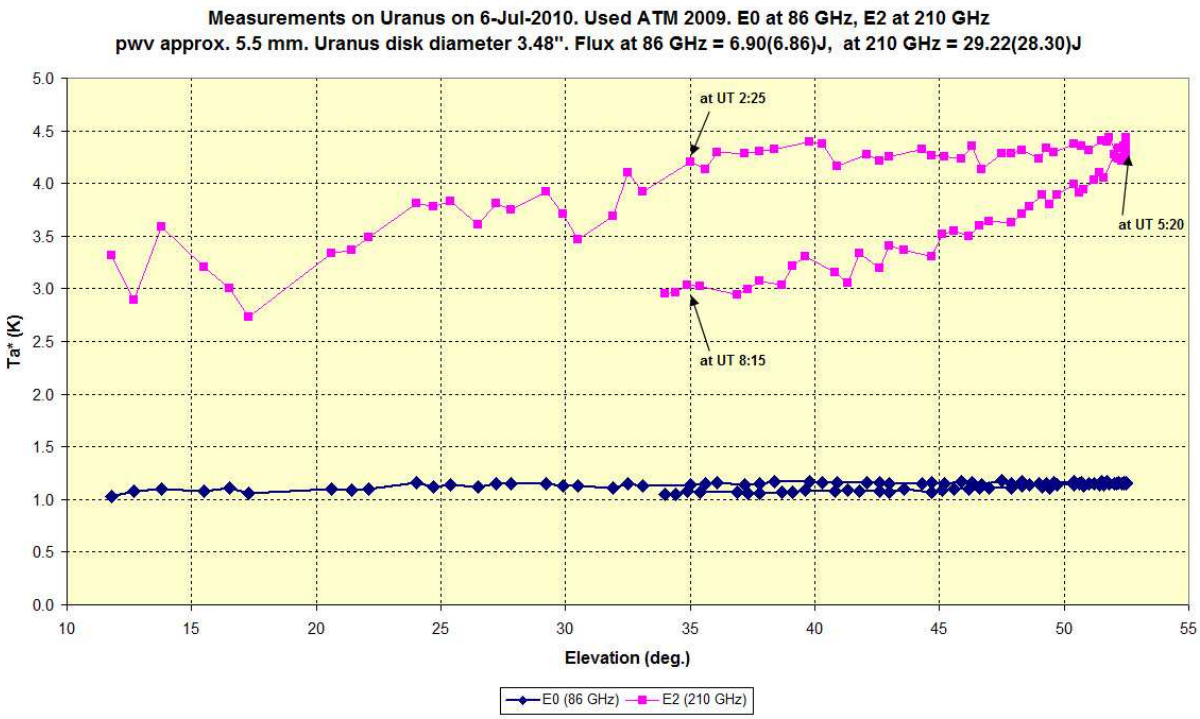

Figure 8: Variation of Uranus peak temperature with elevation (gain-elevation curve) when observing during sunrise, observed with E0/E2 on 6-Jul-2010 by J. Penalver. At 35° elevation and at 210 GHz, the Uranus peak temperature drops by 30% before sun-rise and after sun-rise, while Uranus temperatures at 86 GHz are not affected by the sun-rise, nor by the gain-elevation curve.

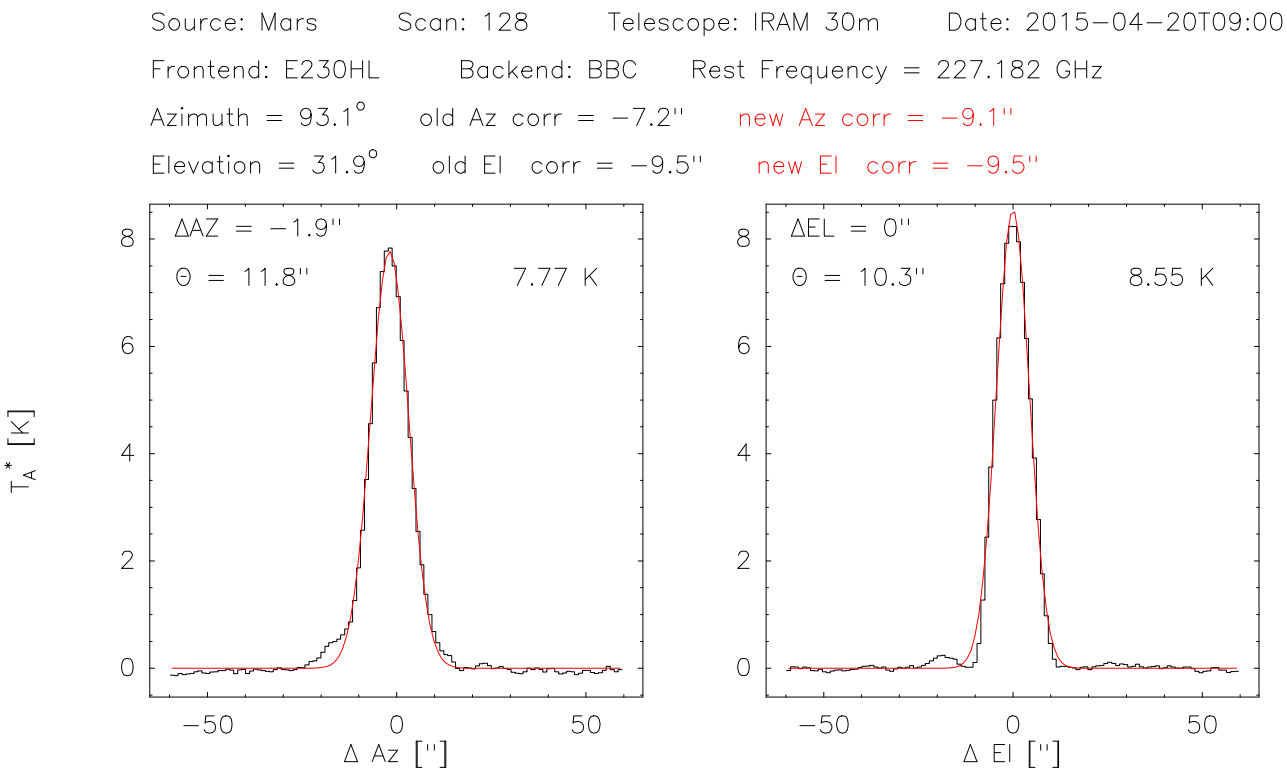

Figure 9: Mars spectrum at 1 mm showing **transient coma-lobes** (20-April).

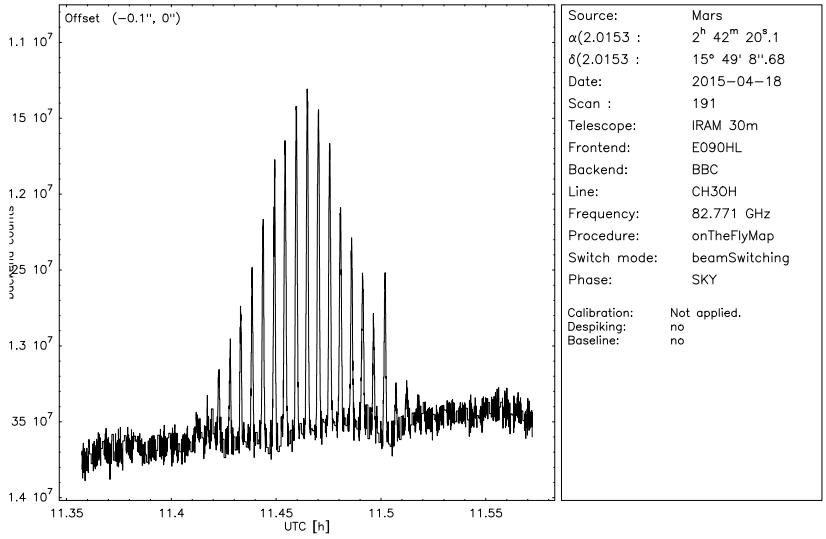

Figure 10: Time series of E090 Mars map taken on 18-April.

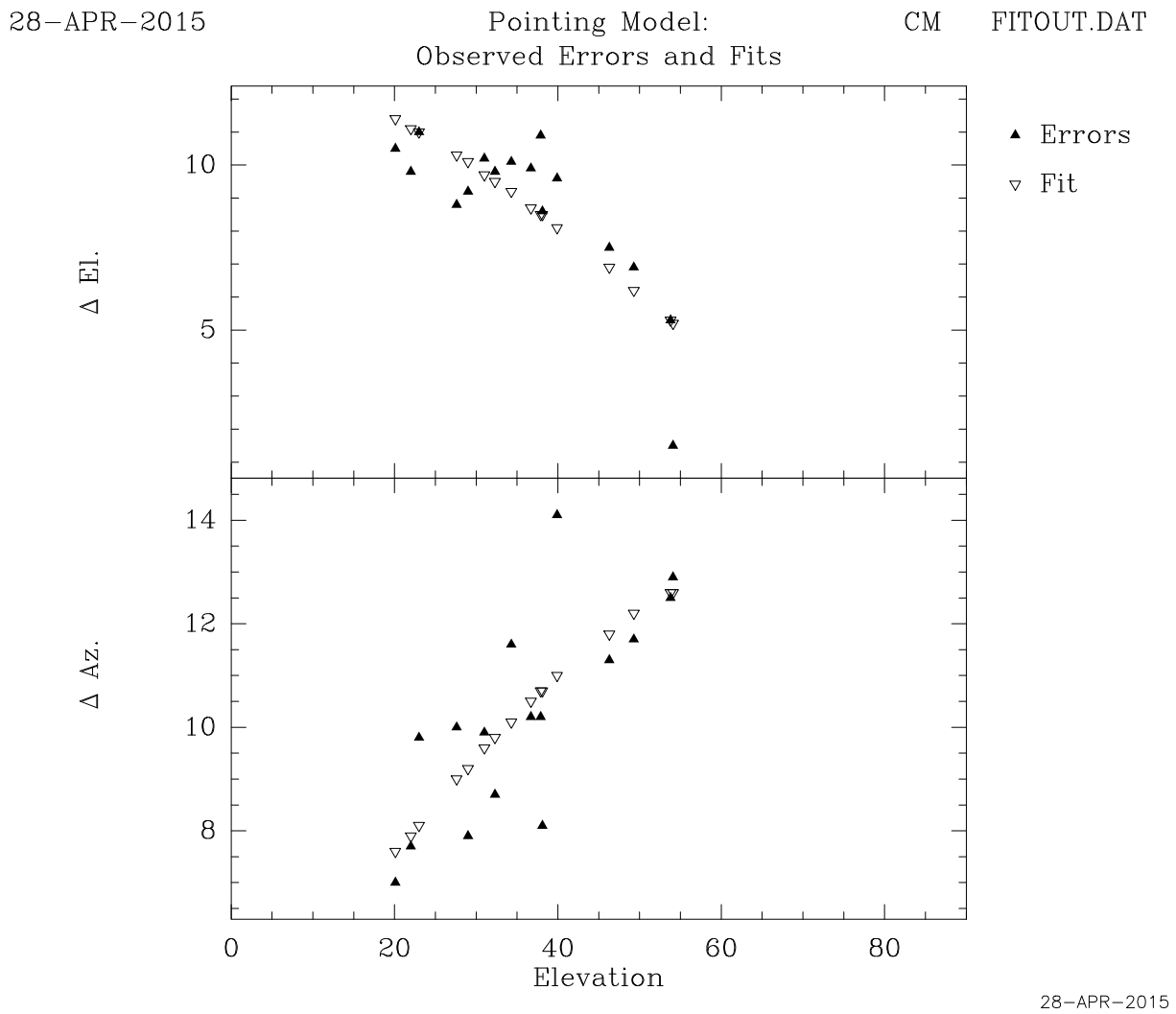

Figure 11: HERA pointing model fit of Nasmyth offsets to 16 positions observed on 28-April.

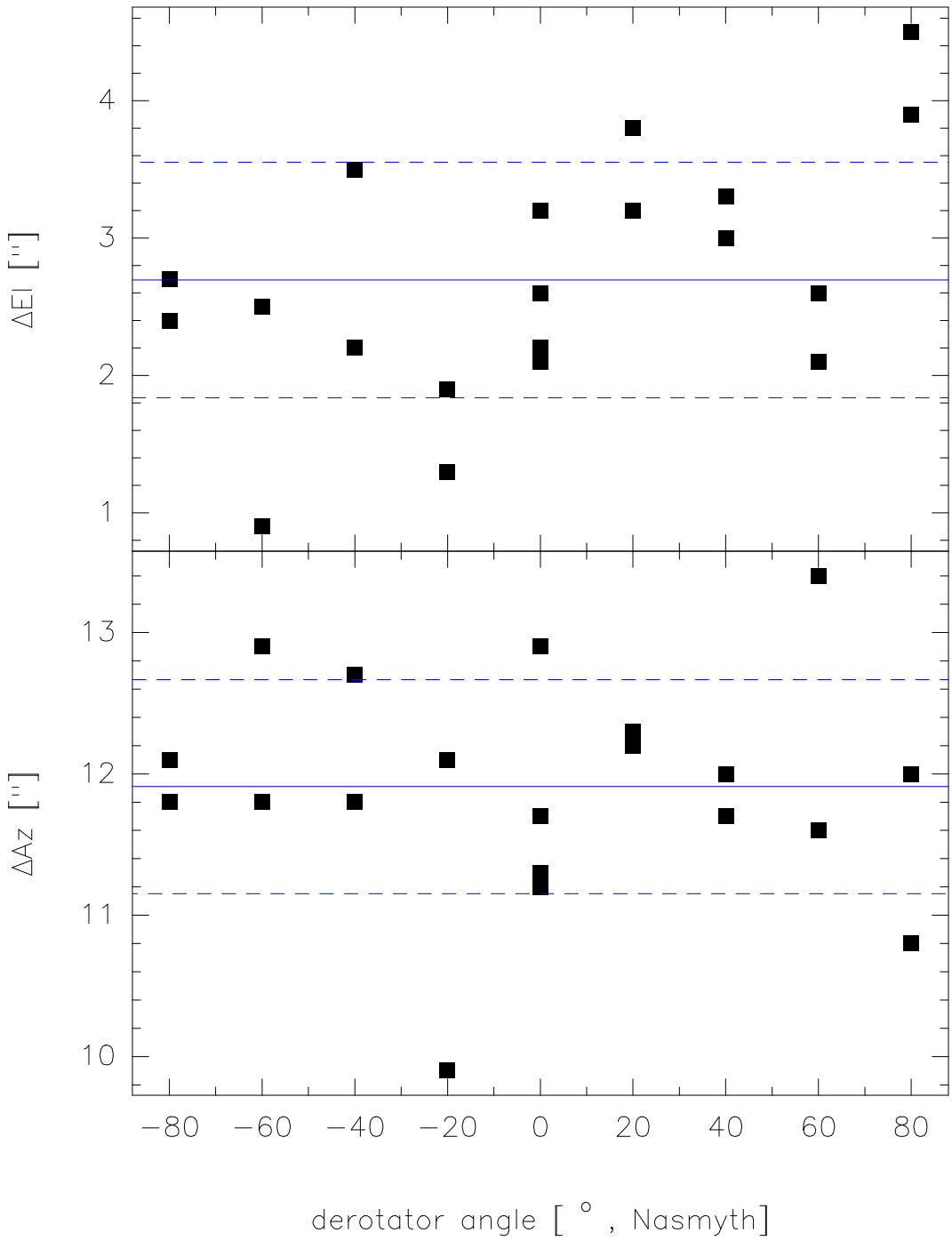

Figure 12: Pointing variation for different de-rotator angles of HERA. Mean and rms are shown as straight and dashed lines. The rms values are $0.8''$ in Azimuth and in Elevation.

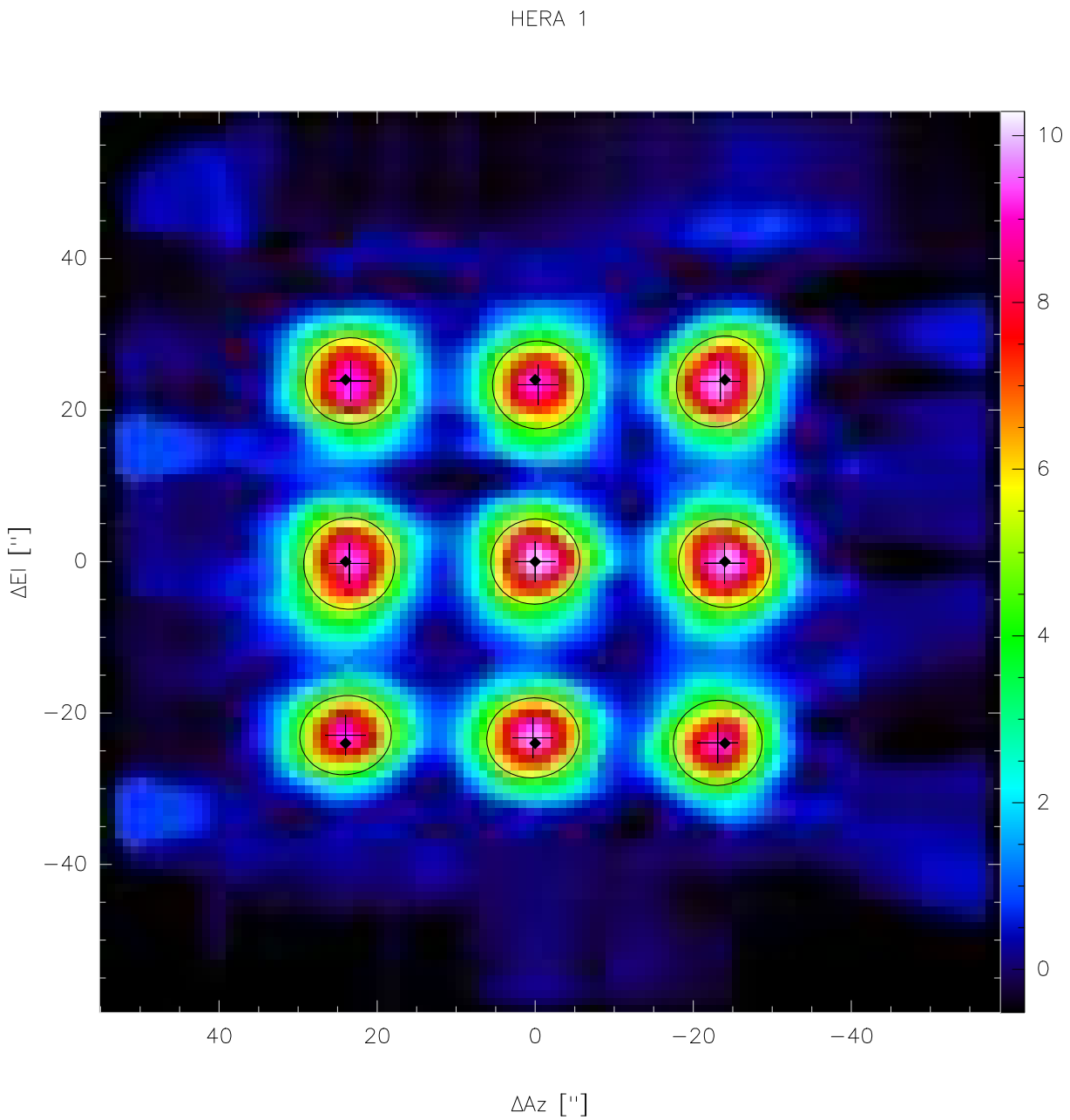

Figure 13: HERA1/NBC Mars map taken on 27-April under excellent weather conditions, albeit shortly after switching-off deicing of the antenna, and during day-time. The map was taken in total power. The nominal pixel spacing is shown (small black marker) together with the results of a Gaussian fitting of position (cross) and FWHM (ellipse). The transition from green to blue marks the $\sim$ 20% contour.

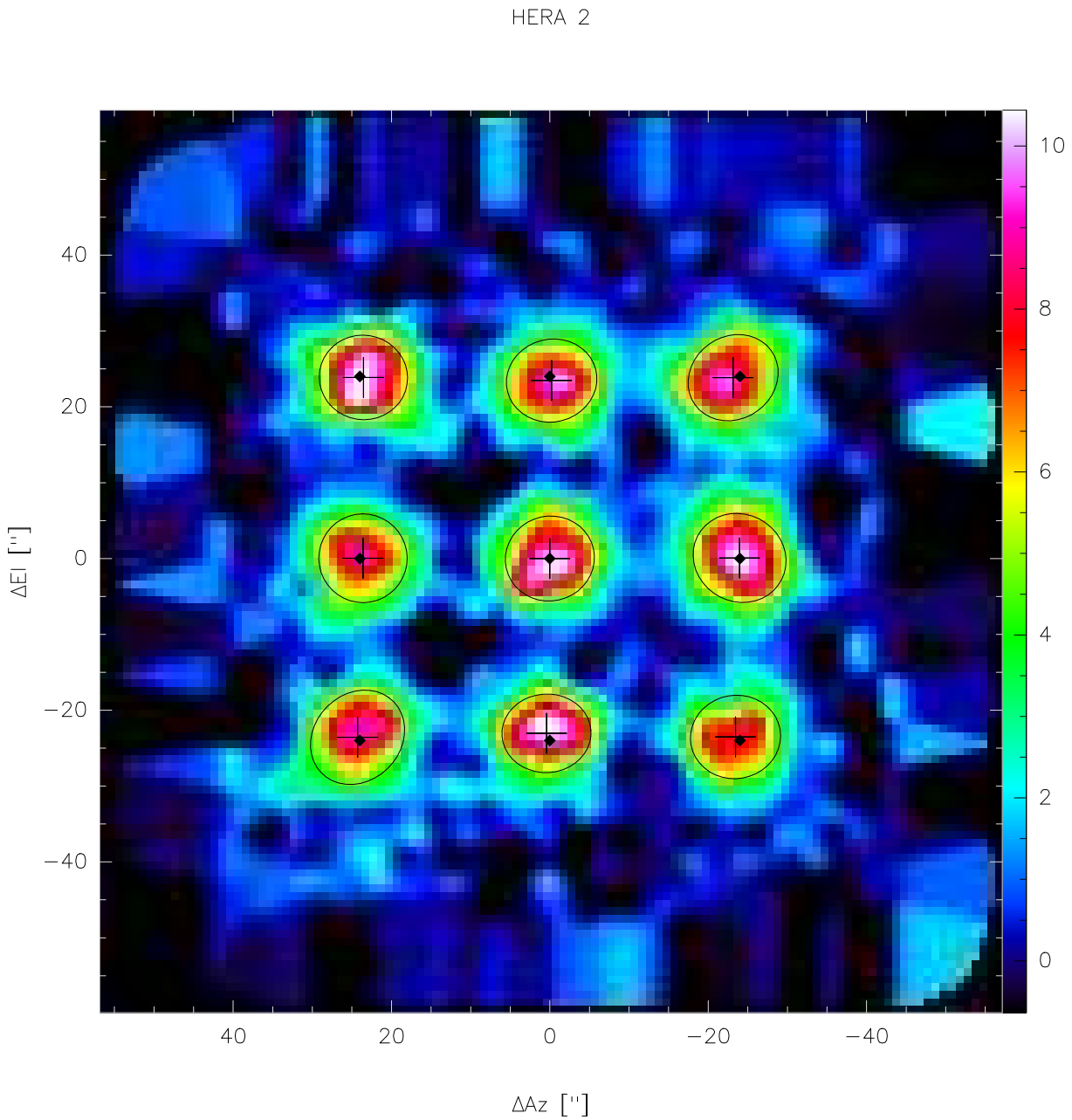

Figure 14: HERA2/NBC Mars map, taken together with the HERA1 map shown above. HERA2 is more instable than HERA1 for this setting. The nominal pixel spacing is shown (small black marker) together with the results of a Gaussian fitting of position (cross) and FWHM (ellipse).

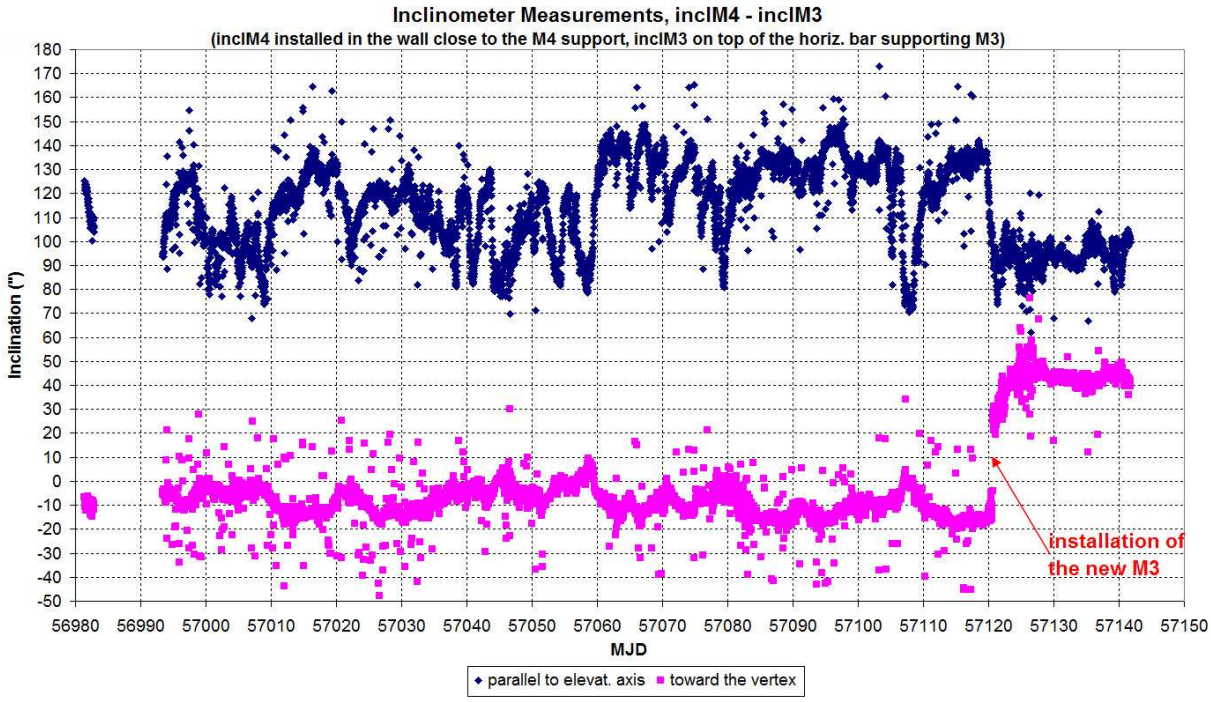

Figure 15: Variation of relative inclination angle between the position of the new M4-Mount and the horizontal bar to which the new M3-Mound is attached. The blue points show the inclination in the direction of the elevation axis. The pink points show the incliation in perpendicular direction, towards the vertex.

2 Commissioning Plan

In April 2015, it is planned to change the optics inside the receiver cabin to adapt it to the enlarged field-of-view of NIKA-2. The current mirrors M3 and M4 will be replaced by new mounts and larger mirrors. The new M4 will be located 15cm nearer to the wall, and also the chopper wheel and its mount. Hence, the first mirrors of EMIR (ME5 to ME7) have to be moved by these 15cm. The EMIR cryostat will not be moved. In addition, HERA and the de-rotator will be moved by the same amount. As one consequence, a new elevation arm will be installed, which connects the M3-mount and the vertex, forcing M3 to follow the telescope movement in elevation. The installation and optical alignment are described in the installation and optical alignment plans [1,2].

After installation and optical alignment, the **radio alignment** may still be somewhat displaced:

1. along the telescope axis leading to a change of focus,
2. by a lateral shift in the focal plan, leading to a pointing offset,
3. by a tilt in the focal plane, degrading the illumination and leading to a loss of aperture efficiency, and,
4. possibly also by rotation about the telescope axis which may affect the positions of the outer HERA pixels. The two EMIR beams are not affected because EMIR mirrors beyond ME7 and the cryostat will not be touched.
5. In addition, the radio beams may be partially blocked along their optical paths (e.g. by the chopper wheel).
6. Further, the alignment may also drift in time, for instance with changing outside temperature.

Suitable observations of the sky and of celestial sources are therefore needed to make sure that these deviations are negligible. Points #1 to #5 need to be addressed during the initial commissioning period in April and requires a couple of days and nights of good, stable weather conditions to move the telescope, do skydips, and to observe primary calibrators and other pointing sources. Point #6 requires a long-term monitoring of some key parameters (pointing, focus) over several months.

The new mounts and mirrors for NIKA-2 (MN5, MN6, MN7) will be installed in May/June, and in any case can only be commissioned with NIKA-2 at the telescope.

2.1 Pre-requisites

Prior to the commissioning, we should clarify with the alignment team:

1. Speak with SN/DJ/SL on how optical alignment went
2. Do visual inspection of new rx cabin optics, especially when doing a full sweep in elevation. How do the elevation arm and M3 follow ? Cables transport via the roof is fine ?
3. Confirm that M4 can be moved by operators into its different positions, in particular into the position for EMIR.
4. Confirm that the chopper can be moved up/down and rotated.
5. Confirm that changing from EMIR to HERA and back by flipping ME5 works
6. Check that the assumptions listed below are justified.

2.2 Assumptions

The astronomical commissioning plan is based on the following assumptions:

1. Optical alignment done and showed no problems.
2. EMIR
    1 Cables to EMIR cryostat have not been revised.
    2 Seperation between the two EMIR beams is unchanged
    3 Alignment between EMIR bands (E0/E2, E1/E3, E0/E1), and between polarisations, was not lost.
3. HERA
    1 Cables to HERA cryostat and de-rotator have either not been revised, or, they have been tested to work again by the installation team.
    2 HERA cryostat/de-rotator alignment was either not lost or they have been opticall realigned.
    3 Separation between the 9 HERA beams is unchanged
4. The HEMT and its mirrors are of no concern here.
5. Skydips work for EMIR and HERA

2.3 Commissioning plan

The aims are to check that EMIR and HERA are fully operational again for astronomy. For this, we need to check that the radio alignment on the sky is ok for EMIR and for all pixels of HERA, that the telescope efficiencies are unchanged, and that there is no blockage. Commissioning shall **start with EMIR**, to get EMIR operational for routine astronomical observations again as soon as possible.

2.3.1 EMIR

1. Check that chopper works for EMIR:

    1 pointing results using the chopper should agree with those using total power and wobbler.

    2 Take a look at individual subscans to identify possible problems with the blanking times (e.g. check for any spikes).

    3 Fluxes using the chopper agree with those using total power and are consistent with those using the wobbler. Note that results using the wobbler are expected to be somewhat smaller, depending on throw.

    4 Measure chopper throw (and position angle). The throw should not be much small than the current value (see section 2.5).

    5 Chopper can be moved out-of-the-way, not creating any blockage for either of the two EMIR beams.

    6 Check that the chopper blades do not block the EMIR beams when we are using a switch mode other than swBeam.

2. do skydips to check for any indications of blockage and to measure the forward efficiency. For upto date telescope efficiencies with the old optics, see the IRAM 30m homepage: `http://www.iram.es/IRAMES/mainWiki/Iram30mEfficiencies`.

3. The following check list may need to be iterated to derive stable, final results.

    1 Measure z-focus, but also check the lateral focus, of EMIR (see current values below). It is sufficient to measure the focus with only one receiver band of EMIR.

    2 Do pointing and z-focus observations at different elevations. Check that focus does not depend on elevation. Are there any indications of blockage by the vertex on one side indicating that the elevation arm is not installed at the correct angle ?

    3 Measure the two EMIR Nasmyth-Offsets by following a point source over a wide range in elevation (see current values below). In principle, they are not expected to change. After implementing revised constants, confirm that EMIR pointing does not change with elevation. Note that the relative offsets (the separation) between the two EMIR beams are not expected to change,

however the two beams may have rotated somewhat on the sky, as M3, M4, ME5 to ME7 were all touched.

4 Measure EMIR aperture and beam efficiencies (and beam widths) and compare with previous values listed on the 30m homepage, which were taken under optimum night time conditions at the optimum elevation. Both EMIR beams should be checked, but one EMIR band per beam (and one frequency) are enough. In principle, the higher frequency bands (e.g. E2 and E3, cf. Section 2.5) are more sensitive to any issues with the new optics. However, they require good weather conditions.

   Note: Don't be distracted by variations due to the gain-elevation curve, the drop of efficiency with wobbler throw, or a drop of efficiency during day-time. Here, we are looking for any drop in efficiency due to poor illumination. Any significant drop would be unacceptable and would need to be discussed with the alignment team.

4. To do additional checks of the correct illumination of the center of the subreflector by EMIR, do pointings at low and high antenna elevations, focussed in z and out-of-focus. Compare with characterization done before the installation of the new optics.

5. Construct new EMIR pointing model by observing > 20 point sources evenly distributed over the sky. If we find important or big changes, we will probably have to iterate two or more times. We don't need to do a separate pointing model with HERA, as EMIR and HERA only have different Nasmyth offsets.

6. Check that XPOL with EMIR/VESPA is still working (external cold load, grid). Some mirrors will be moved towards the wall, which may increase spillover, and the total pathlength will change by $+25$ cm (SN, priv. comm. 9-Feb), but the relative path between H/V should not change.

   1 The external LN2 calibration unit will be moved. For a correct XPOL calibration one of the mirrors of the EMIR warm optics redirects the beam into the LN2 bucket. It has to be positioned in front of the left or right dewar window depending on which EMIR band is used. Check: make an XPOL calibration in each of the two EMIR bands and look at the power recorded in subscans #3 and 4.

   2 Correct alignment of LN2 bucket. It should intercept all of the EMIR beam, only then is the effective temperature of the LN2 load near 80 K (contact Santiago). check: make a calibrated observation at 3 and 2 mm of a continuum calibrator. Verify that Tcold = 80 K gives the right flux.

   3 Do we still get correlated power ? check: make an XPOL calibration in each of the 4 bands. Then look at data with mira using command view 1 (or 2) /xpol Amplitude should be around 100 K (i.e. 50% of HOT - COLD)

4 Is EMIR (each one of the two windows) still well centered on the radio axis ? Only then the on-axis instrumental polarization is low. Check: make XPOL observations of a strong unpolarized source (Mars, Uranus). Analyze with `CLASS> @ xpol`.

5 Does EMIR pick up more power in the sidelobes through its new optical path ? This power is likely considerably polarized and may thus adversely affect the level of the polarized sidelobes. Check: make small beam maps (Mars or Uranus). Compare with maps done previously with old optics: `http://www.iram.es/IRAMES/mainWiki/PolarimetryforAstronomers`

7. In case of problems, it is recommend to tackle them, rather than moving-on to work on HERA. If all of the above have been positively tested, we'll need to start monitoring the long term evolution of the pointing. There may be drifts because M3 and M4 are now mounted differently. See the report by JP [5] on the relative movement of the inclinometers at the new mount positions, done prior to installation.

8. Aside from the long term monitoring, EMIR is available again for routine observations.

2.3.2 HERA

The aim of the following tests is to check that HERA is well aligned on the sky, after moving it by 15cm towards the wall of the receiver cabin. In addition, the plan below describes how to check the radio alignment between the HERA cryostat and the de-rotator in case it was lost. In any case, we assume here that the alignment team have already realigned the de-rotator optically with lasers, that the de-rotator can be controlled using PaKo, and that the chopper wheel was already tested using EMIR.

Pointing with the central pixel The goal of this test is to check that the pointing offsets, the FWHM, and the flux peak of the central pixel do not change for when changing the elevation and/or the angle of the de-rotator. Testing at only one HERA 1+2 frequency is sufficient.

1. Go to a strong pointing source (Mars is probably optimal).
2. To avoid uncertainties (e.g., anomalous refraction) might be useful to set the number of subscans to 8 or more.
3. Measure the chopper throw. It should be the same as for EMIR. Check that the chopper wheel can be moved out of the way, without creating any blockage. Do a skydip to confirm this. Repeat at different elevations. Measure at the same time the forward efficiency. If at all, blockage may be more of an issue for the outer HERA pixels.
4. Check that the chopper blades do not block any of the HERA beams when we are using a switch mode other than swBeam.
5. Measure carefully the pointing and the focus corrections with the de-rotator angle set to 0. In case the pointing of the central pixel changes with elevation, this may indicate an Nasmyth offset of HERA, which would need to be measured and implemented into NCS.
6. Check pointing for entire range of derotator angles in steps of 15 degrees. For each pointing scan, write down the pointing offsets, the FWHM, and the flux peak. Check also the shape of the beam for any deviations from a Gaussian (e.g. for sidelobes). Compare with Figure 3 in [7].
7. Check pointing over entire elevation range.
8. If possible, it would be good to repeat some pointings using wobbler and total power switching modes in order to check that the pointing results are the same. Note that resulting fluxes using the wobbler may be somewhat smaller, for large wobbler throws.

Geometry map The aim of this test is to check the position on the sky of the 9 pixels of HERA.

1. Set the observing mode to track+swbeam.

2. Set the de-rotator tracking the sky ($\mathrm{PAKO} > \ \mathrm{receiver\ hera1\ /derot}\ \beta\ \mathrm{S}$).

3. Do a long integration in order to check that the 9 HERA pixels do not change their position on the sky when changing the elevation of the source. Probably it is a good idea to start/finish this test 1 hour before/after the transit.
   Note: *This needs to be elaborated: observing mode?, parameters? data processing? probably NOT track+swbeam!*

4. Measure the position of the pixels on the sky (CLASS, go where) and check that their position is fixed.

5. Repeat the test for different de-rotator angles (e.g., β, $\beta + 30$ and $\beta + 60$).

Further tests

1. The chopper might block the HERA outer pixels. To check this we should do skydips at three different angles (e.g., β, $\beta + 30$ and $\beta + 60$) and over the full elevation range. Useful information to do this test might be found in [6].

2. If all the previous test were done successfully, go to a bright, extended source (e.g., the Orion bar) and launch an otf map using the line backends. Once the map is done, compare it with previous observations or with data from other telescopes (e.g., Planck). [Comment: Planck resolution is not sufficient for this. Better prepare for using previous 30m maps. (CK)]

2.4 Sources

1. Planets: Mars and Uranus are available. They are bright and (in 4/2015) pointlike. Mars currently has a diameter of 3.8" culminating at 70deg in elevation at 13:20. Uranus has a diameter of 3.1" culminating at 59deg at 11:30.

2.5 Values before installation of new optics

1. Nasmyth-offsets

   - EMIR: Current Nasmyth offsets [3] (Comm.Report 5/2009)
     Right beam: $39.0''/+5.5''$ E0, E2, E0/E2, E0/E1
     Left beam: $+51.0''/+5.5''$ E1, E3, E1/E3
   - HERA: Nasmyth offsets of central pixels: 0/0
     Nasmyth offsets of outer pixels: $24''$ (cf. HERA user manual)

2. Typical focus values

   HERA: -2.7mm
   EMIR: -2.7mm

3. Chopper: The throw is about $170''$ as of March 2015. Its position angle is unknown.

3 References

1 New optics installation plan, S. Navarro

2 New optics alignment plan, S. Navarro

3 EMIR commissioning report, May 2009

4 HERA user manual (v2.0), April, 4, 2006

5 Relative inclination between the future mounts of M3 & M4, J. Penalver, Spring 2015

6 Reference to J. Peñalver report on the chopper blockage.

7 A 230 GHz heterodyne receiver array for the IRAM 30 m telescope, K. F. Schuster et al., 2004 (A&A).

8 Pointing and thermal behaviour of the IRAM 30m telescope by A. Greve (p.41, Fig. 1a), Workshop on Pointing and Pointing Models, March 7 and 8, 1996, W.J. Altenhoff, Technischer Bericht Nr.78, MPIfR, ISSN 0939-3153

9 Long-term 90 GHz observations of Uranus and Neptune, C. Kramer et al., 2008, A&A, 482, 359

10 Calibration of spectral line data at the IRAM 30m telescope, C. Kramer, 1997, IRAM Report

11 Herschel celestial calibration souces. Four large main-belt asteroids as prime flux calibrators for the far-IR/submm range. T. Müller et al. 2014, Experimental Astronomy, 37, 2, 253

12 Jaap Baars, 2007, The Paraboloidal Reflector Antenna in Radio Astronomy and Communication