Polarization performances of the new Medicina 5-GHz system

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1 Introduction

This paper reports the polarization performance analysis of the new 5-GHz system installed in (boreal) Summer 2006 at the Medicina radio telescope. All of this analysis have been done using data taken in the July 2006 observation run (17-27 July 2006).

The analysis has been done at 3 frequencies (5120, 5050, and 5800-MHz) to cover the working frequency of the Galactic emission observation project (5120-MHz, e.g. 1-06 Carretti project), and both the central and high-end frequency of the receiver band (5050 and 5800-MHz, respectively). Severe RFIs prevent us to take reliable observations at the low-end frequency of 4300-MHz: neither observations of the calibrator (3C 286) were successful. The Medicina polarimeter with a 80-MHz bandwidth (3dB width; the effective bandwidth is 56-MHz) has been used.

Here below we report on-axis and off-axis instrumental polarization data for all of these cases. The sensitivity have been measured only for the working frequency of 5120-MHz. Only here we have been able to find a frequency range free from RFI large enough to fit the whole 80-MHz bandwidth of the polarimeter and make reliable measurements. A summary of all of the relevant parameters is reported in Table 1. Performances of the old 5-GHz system have been also presented in that Table for comparison. In this case, the observation frequency was set to 5070-MHz (same polarimeter bandwidth). That was the highest and the most RFI free frequency range reachable by the old system. The new system observations have been set to 5120-MHz, because even more free from RFIs. Actually, the presence of RFI contaminations even at 5070-MHz and the need for cleaner frequencies was one of the main reasons to move to the new system (about our polarization project).

Table 1: On- and off-axis instrumental polarization of the new 5-GHz system of Medicina. The Q and U 1-second sensitivity $\sigma_{1s}^{Q,U}$ of the 80-MHz band centred on 5120-MHz is also reported. Note: off-axis instrumental polarization of the 5120-MHz case is actually measured at 5145-MHz – see text. Performances of the old 5 GHz system at 5070-MHz are also reported for comparison.

frequency [MHz]	On-axis instr. pol. [%]	Off-axis instr. pol. [%]	$\sigma_{1s}^{Q,U}$ [mK s$^{1/2}$]
5050	0.87	1.0	
5120	0.51	0.7	3.6
5800	0.73	2.5	
(old 5-GHz)			
5070	0.73	1.4	5.4

2 $\nu = 5120$ MHz

2.1 On-axis instrumental polarization

The calibrator 3C 286 has been observed for a time longer than 4 hours around the transit (on 18 July 2006). Parallactic angle variations over the observation modulate the polarization signal of the Stokes parameters Q and U like sinusoids (Figure 1). The offset of the sinusoid is the on-axis instrumental polarization. From fit of a sinusoid and a constant value, we get the following instrumental polarization fractions (defined as instrumental polarization-to-total intensity ratio) for Q, U and the polarized intensity $L = \sqrt{Q^2 + U^2}$:

1. $Q_{\rm offset}/I = 0.27\%$
2. $U_{\rm offset}/I = 0.59\%$
3. $L_{\rm offset}/I = 0.66\%$

where I is the total intensity signal and $Q_{\rm offset}$, $U_{\rm offset}$, $L_{\rm offset}$ is the instrumental polarization (sinusoid offset) of Q, U, L, respectively.

Thus, a 0.66% on-axis instrumental polarization is measured.

Such offset values are small with respect to the polarized signal of 3C 286. The fit offset is thus much smaller than the sinusoid amplitude and its value can have some uncertainty. Therefore, a strong unpolarized source has also been observed: DR21. In this case, all the detected polarized signal is instrumental polarization.

Fit of its data provides the following results:

1. no significant signal modulation has been detected (confirming the assumption of unpolarized source);
2. $Q_{\rm offset}/I = 0.16\%$
3. $U_{\rm offset}/I = 0.46\%$
4. $L_{\rm offset}/I = 0.51\%$

The value of $L_{\rm offset}/I$ is not so far from the previous measurement, making us confident that even to fit the offset of 3C 286 provides reliable results.

A comparison with the old 5-GHz system is done in the 5050-MHz section (Sect. 3). This frequency and the 5120-MHz analysed here bracket the observing frequency of the old system (5070-MHz).

2.2 Off-axis instrumental polarization

The off-axis instrumental polarization is measured mapping a strong unpolarized source, namely DR21 (on 22 July 2006). Measurements at 5120-MHz are not available. However, observations have been performed at the close frequency of 5145-MHz. The shift of 25-MHz is smaller than the polarimeter bandwidth (80-MHz) and the results can be considered representative of the 5120-MHz case. Images of DR21's I,Q and U at 5145-MHz are displayed in Figure 2.

The typical quadrilobe patter is visible on both Q and U, with the Q one oriented along the main axes, while U's is 45° rotated.

The peak of the off-axis instrumental polarization is about 0.7%.

We plan to map DR21 also at 5120-MHz next observing runs to have a full characterization of the working band of our project.

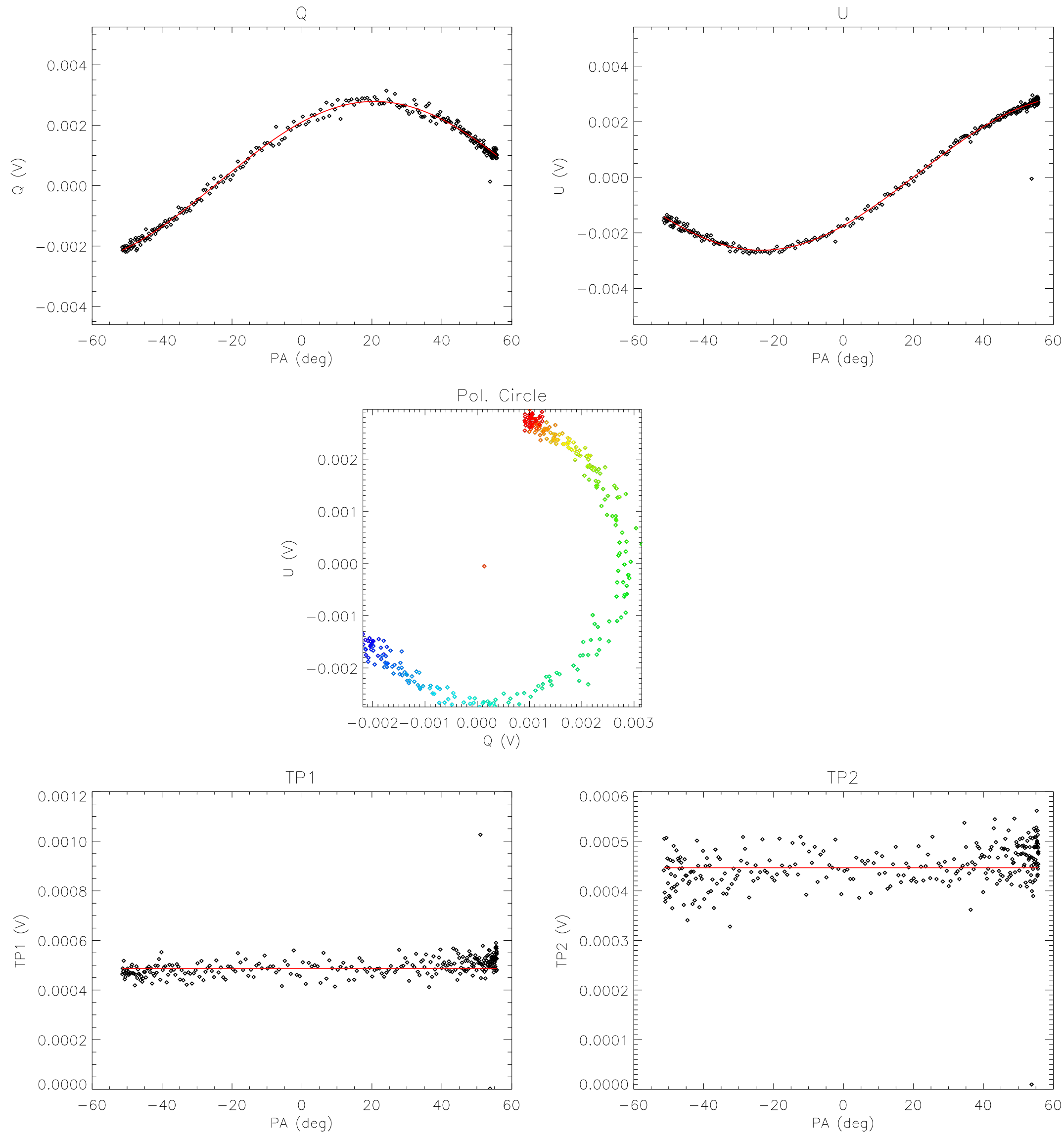

Figure 1: Q and U Stokes parameters versus Parallactic Angle (PA) of 3C 286 observations at 5120-MHz. Data are before calibration and are in Volt (ADC output). The polarization circle (U versus Q) and the two total power signals (TP1 and TP2, i.e. Left and Right polarization) are also reported.

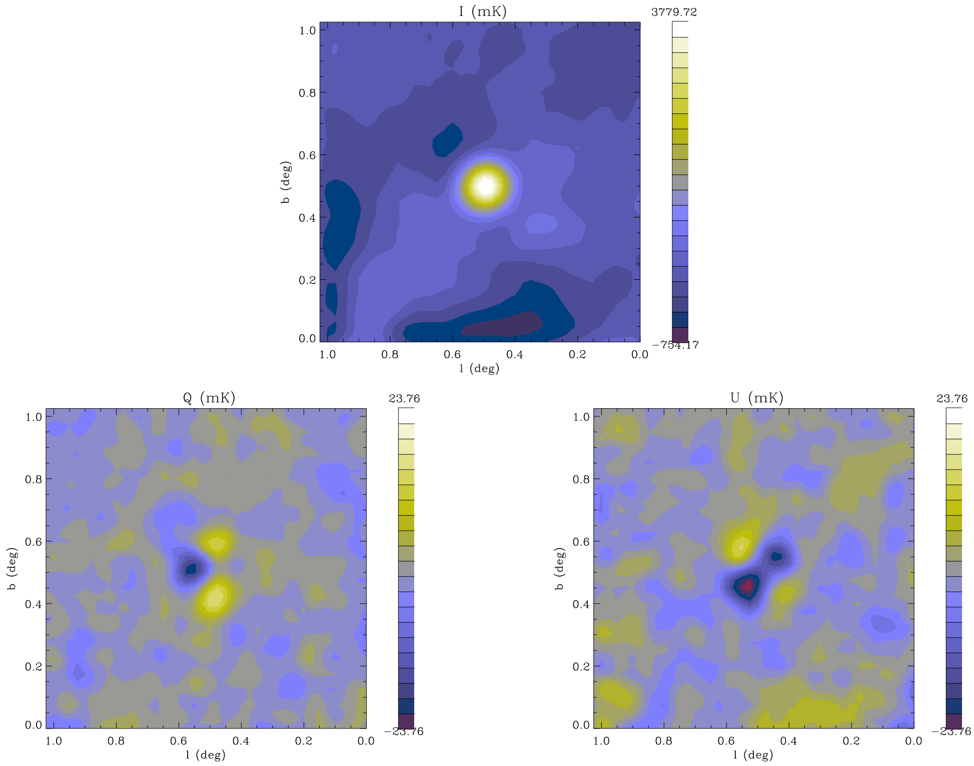

Figure 2: I, Q and U images of DR21 at 5145 MHz. Units are mK.

2.3 Sensitivity

A power spectrum analysis has been performed of North Celestial Pole (NCP) observations (See Figure 3). Data were taken on 23 July 2006. The power spectrum at 1-Hz is 13-mK^2 Hz^{-1}, that means a 1-second sensitivity of $\sigma_{1s} \sim 3.6$ mK s$^{1/2}$. However, besides the drop-off at frequencies larger than 1-Hz because of the low-pass filter, the power spectrum of both Q and U looks steep. That means a 1/f noise component is present. The slope is flatter than expected (about 0.5 instead of 1.0) and the origin of this component is still unclear.

A comparison with the spectra of the old system (Figure 4) can tell us something more. In this case both Q and U spectra show the white noise plateau, with the $1/f$ component starting at $\nu_{\rm knee} < 0.1$-Hz. The plateau corresponds to a sensitivity of $\sigma^{Q,U}_{1s,{\rm old}} = 5.4$ mK s$^{1/2}$, indicating that the new 5-GHz system is a significant improvement with respect to the old system.

Moreover, extending the Q and U spectra of Figure 3 to lowest frequency, values of $P \sim 100$-mK^{2}Hz^{-1} can be derived at $\nu = 0.01$-Hz. These amplitudes are suspiciously similar to those of the old system. Therefore, this seems to indicate that the 1/f component is common to the two systems, meaning that could have an external origin (atmospheric fluctuations? 1/f noise of the polarimetric backend? To be further investigated in future). The old system has a worst sensitivity, so that the white noise plateau dominates the 1/f component at $\nu = 0.1$–1.0-Hz. The new system, instead, has a *too good* sensitivity and the white noise plateau sets below the 1/f component even at 1-Hz. (Medicina engineers have done a too good job!) In other words, we would not yet be seeing the receiver noise, but some other component. The independent $T_{\rm sys}$ measurements done at the installation time seems to match this framework: an improvement of better than 2 has been seen, that would lead to a $\sigma^{Q,U}_{1s} < 2.7$ mK s$^{1/2}$, versus the 3.6 mK s$^{1/2}$ actually measured by the spectra.

Measurements with a higher frequency sampling would be necessary for further investigations. However, this would require a change of the low-pass filter (the integrator) of the polarimeter, whose effects are already visible in the spectra (the drop down at $\nu > 1$-Hz). In fact, it would be needed to change the low-pass filter frequency from 3 to 30-Hz.

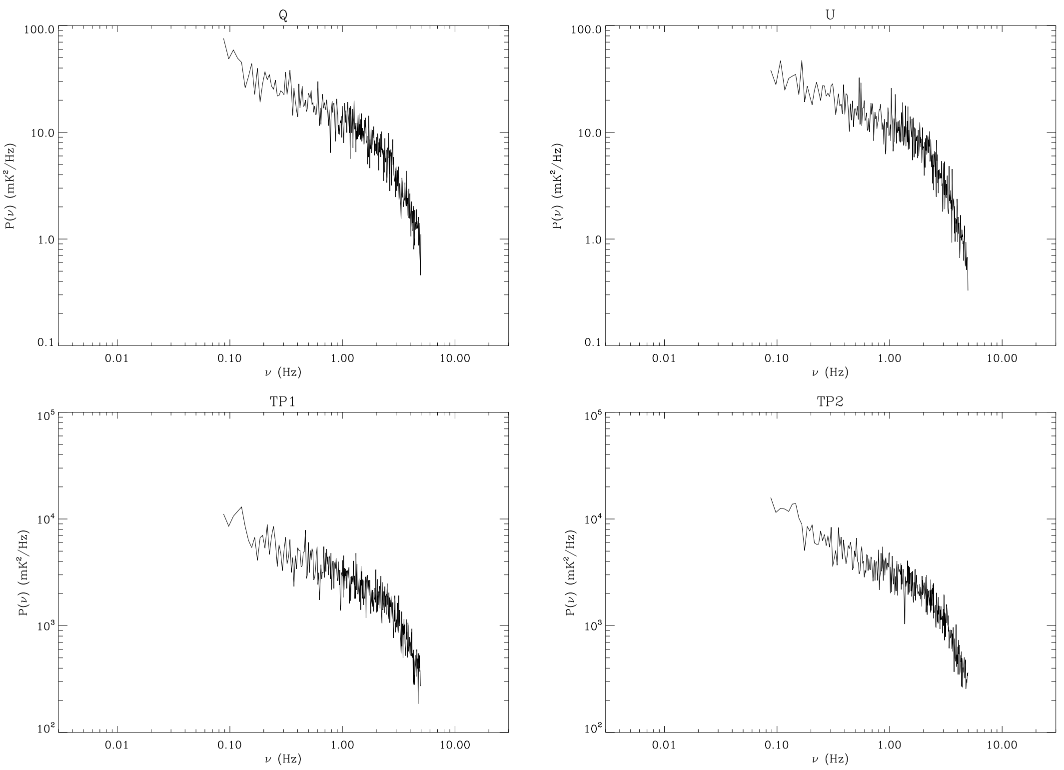

Figure 3: Q, U, $TP1$, and $TP2$ power spectra of the north celestial pole observations at 5120 MHz.

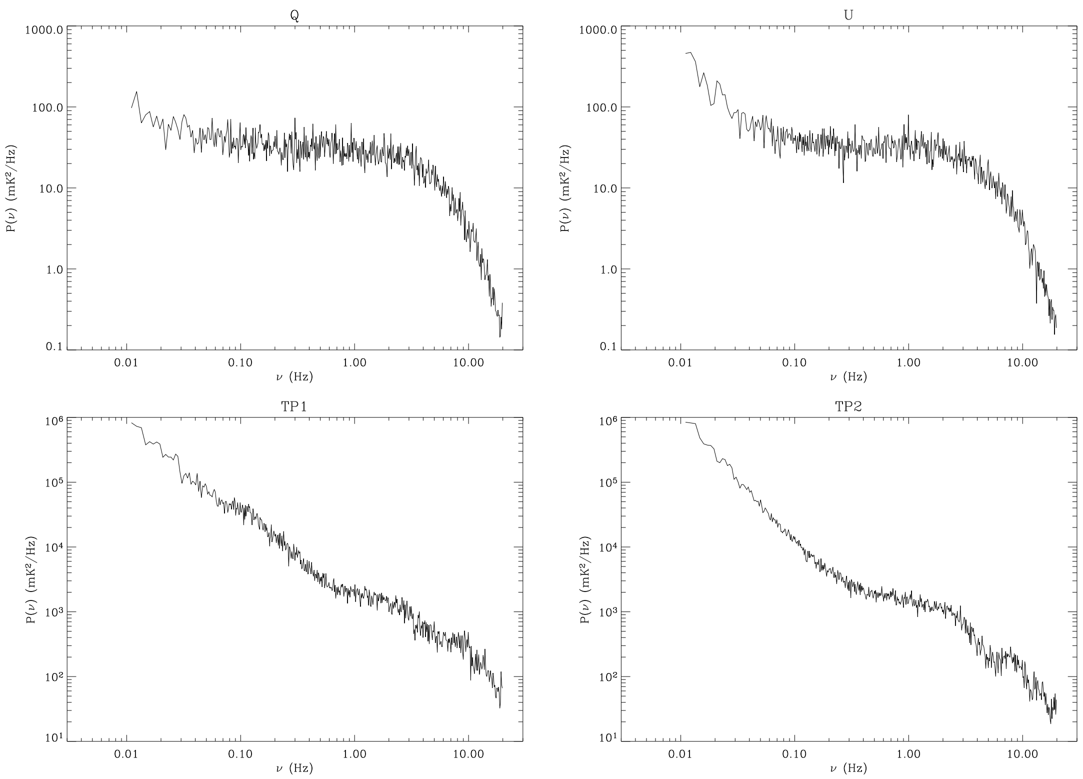

Figure 4: Old 5-GHz system: as for Figure 3 but for the old 5-GHz system at 5070 MHz. These north celestial pole observations were taken on 1^{st} Jan 2004.

Finally, power spectra of the two Total Power outputs (TP) are similar, but about 250 times larger than the polarized ones. That means TP sensitivities are $\sim$ 55 mK $s^{1/2}$.

3 $\nu = 5050$ MHz

3.1 On-axis instrumental polarization

The calibrator 3C 286 has been observed at 5050-MHz on 23 July 2006. Modulation of Q and U Stokes parameters versus PA are reported in Figure 5.

From fit of a sinusoid and a constant value, we get the following instrumental polarization fractions

1. $Q_{\rm offset}/I = 0.84\%$
2. $U_{\rm offset}/I = 0.24\%$
3. $L_{\rm offset}/I = 0.87\%$

where I is the total intensity signal.

It is worth noting that the results both at 5050 and 5120-MHz are similar to the performance of the old system at 5070-MHz (0.73%), which already exhibited very good performances in this respect (at these frequencies, at least).

3.2 Off-axis instrumental polarization

The off-axis instrumental polarization is measured mapping DR21 at 5050-MHz on 23 July 2006. Images of I, Q and U are displayed in Figure 6.

Also here the quadrilobe pattern is visible and the peak of the off-axis instrumental polarization is about 1.0%.

The comparison of the 5050 and 5120-MHz results with those of the old system shows an improvement by a factor of about 2.

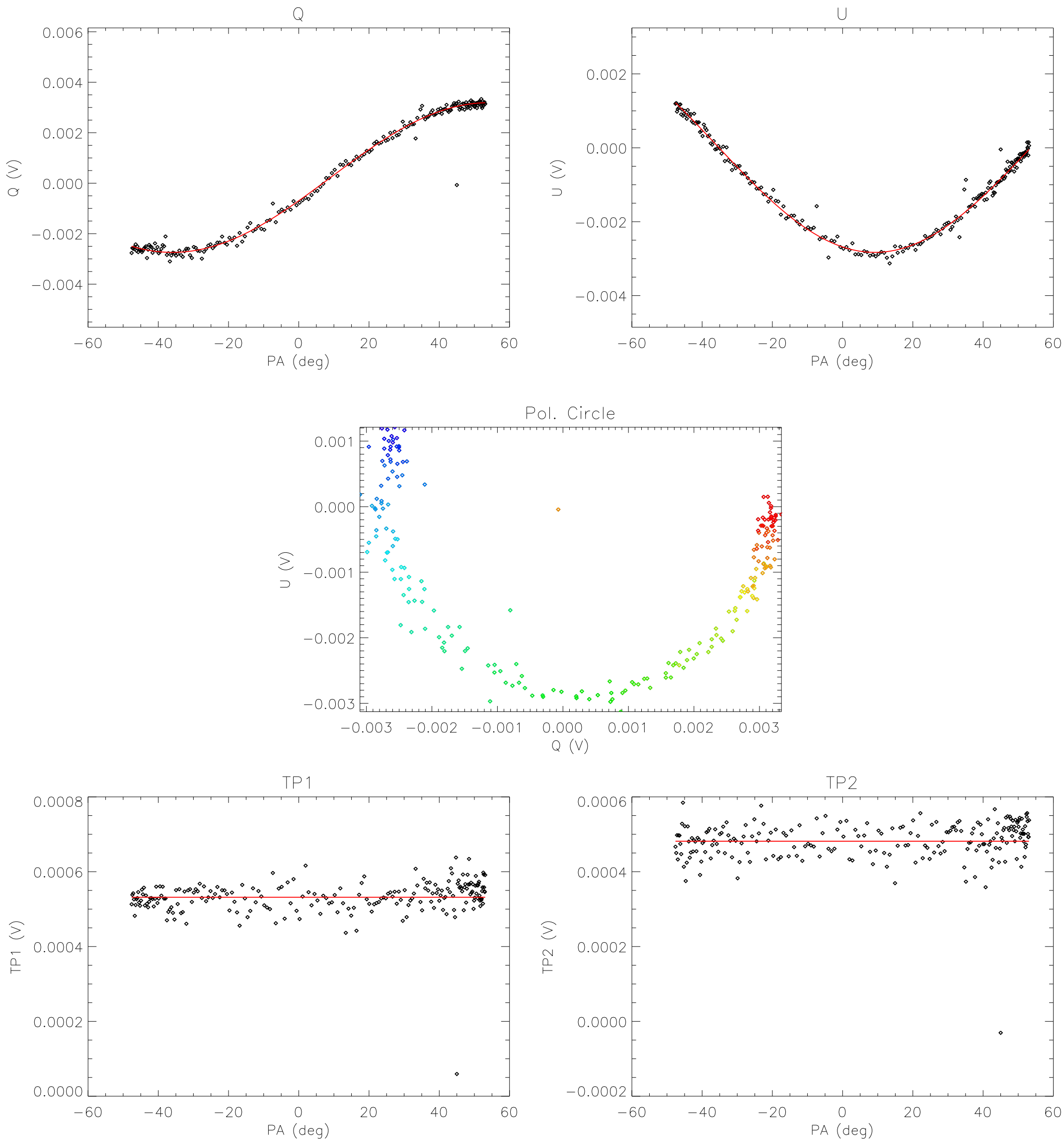

Figure 5: As for Figure 1 but at 5050-MHz.

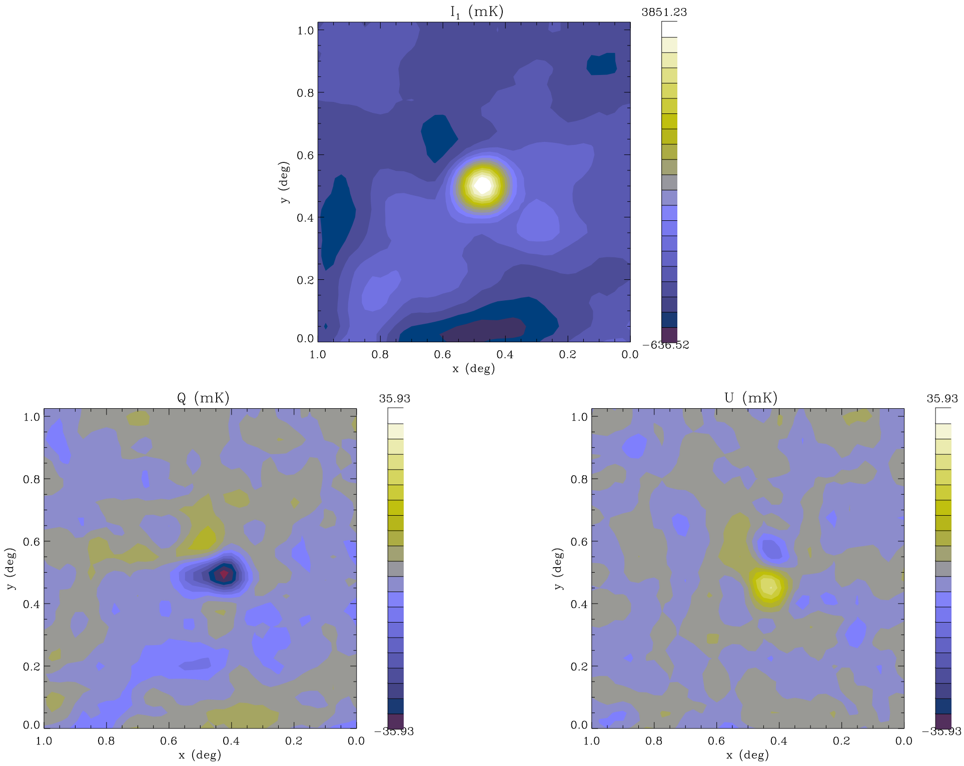

Figure 6: I, Q and U images of DR21 at 5050 MHz. Units are mK.

4 $\nu = 5800$ MHz

4.1 On-axis instrumental polarization

The calibrator 3C 286 has been observed at 5800-MHz on 24 July 2006. Modulation of Q and U Stokes parameters versus PA are reported in Figure 7.

Conditions are worse than both at 5050 and 5120-MHz, most probably because of the action of close RFIs. However the signal is strong enough to allow the sinusoidal fit. From this we get the following instrumental polarization fractions:

1. $Q_{\rm offset}/I = 0.17\%$
2. $U_{\rm offset}/I = 0.70\%$
3. $L_{\rm offset}/I = 0.73\%$

The reliability of such results, however, is not stated, because of both the low values and the bad quality of the data contaminated by RFIs. We plan to better measure them by using a strong unpolarized source (e.g. DR21), as we did at 5120-MHz.

4.2 Off-axis instrumental polarization

We attempted to measure the off-axis instrumental polarization by imaging DR21 (on 24 July 2006). The frequencies around 5800 MHz are affected by RFI, resulting in a bad and not usable DEC map. From RA scan only data we estimate a peak off-axis instrumental polarization of $\sim 2.5\%$.

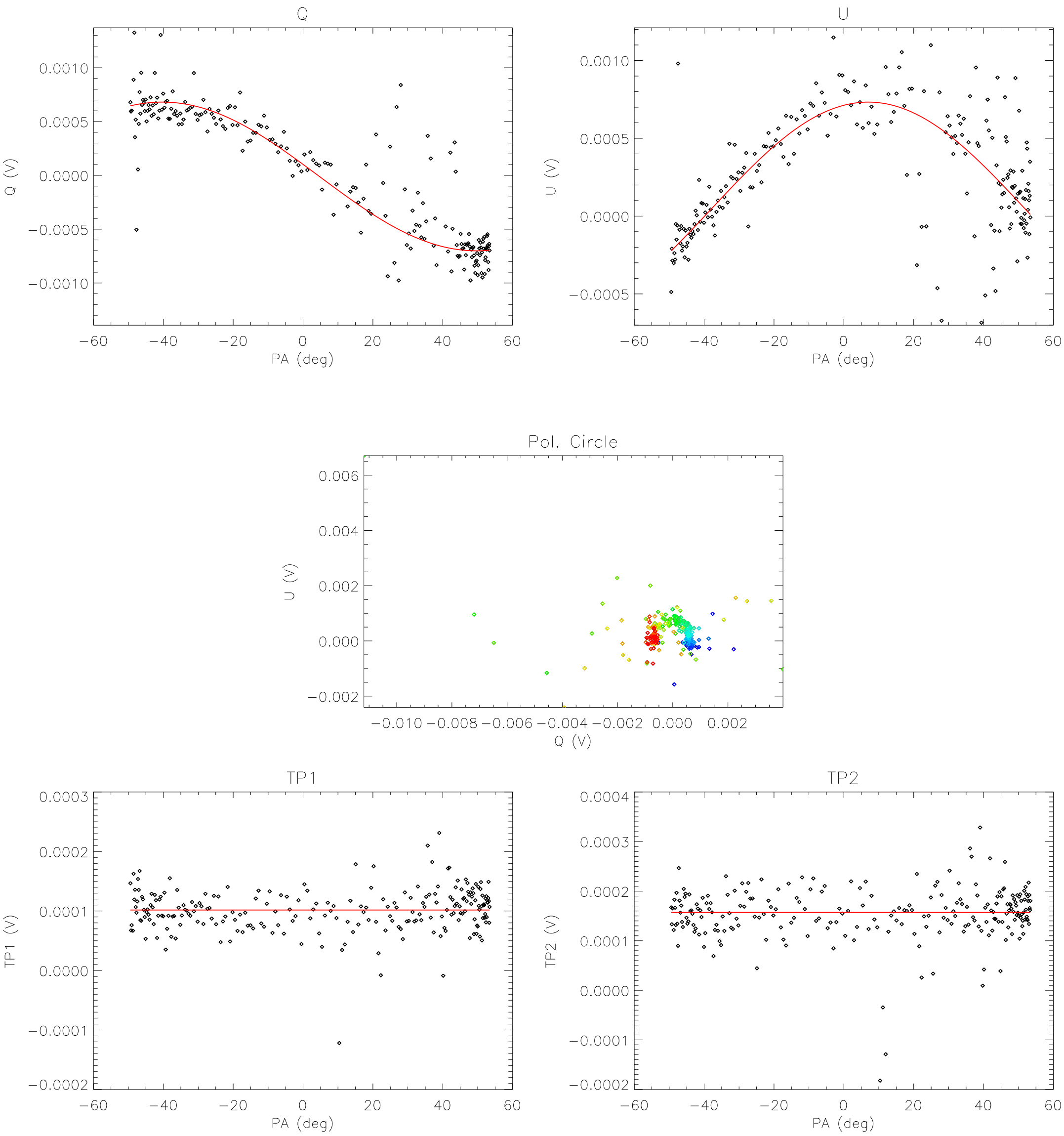

Figure 7: As for Figure 1 but at 5800-MHz.