Baseline model for wide field of radio sky

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We present a new empirically found model of emission of radio waves from the environment of the radio telescope, recorded systematically during observations carried out within the framework of the Toruń Polarimetric Survey (ToPoS) at the frequency of 4.7 GHz, using a 32-metre radio telescope. Here we present the formulas describing the unwanted level of total and polarized power. The linearly polarized component is described by a different empirical model than the one found for total power.

1 Introduction

Measurements of the intensity of radio waves coming from space using a single dish radio telescope shall be corrected for the influence of the Earth's atmosphere. Most observers use the old formula of the transfer equation (cf. Rohlfs & Wilson, 2004), which does not work properly when mapping a large area of the sky. Several methods have been developed to avoid scanning effects due to different atmospheric thicknesses - such as mosaic mapping (Reich et al., 1990), observation with a fixed position of the telescope looking at the moving sky (Wolleben et al., 2006), etc - to limit scanning effects due to different atmospheric thicknesses.

When mapping the sky for the ToPoS project, we cover the area $20^\circ \times 20^\circ$, i.e. we make scans 20° in length. The observations showed that the model taking into account only the influence of the obscuration (absorption and emission) of radio waves by the atmosphere is insufficient to correct the recorded data. This is caused by the side lobes of the radio telescope - receiving radiation from all directions (full sphere - half of which is the surface of the Earth). Therefore, we have to take into account the model of radiation from the surface of the Earth - more precisely all the radiation from the environment of the radio telescope. This undesirable level of additional radiation is called the "baseline".

In order to determine the dependence of the base line on the position of the radio telescope, several scans were made from zenith to horizon. All observational data were corrected for non linearity of the receiver (less than 0.5%), amplification changes (less than 1%) and parasitic inter channel leakage using Müller's matrix formalism (cf. Cenacchi et al., 2009). The corrected data were used to search for a better possible model.

2 Total power dependences

The formula for optical depth τ at a selected distance from the zenith z can be calculated by adopting the model of spherical symmetry of atmospheric density. In the field of radio astronomy a good approximation is a solution in the form of a series of (cf. Rohlfs & Wilson, 2004):

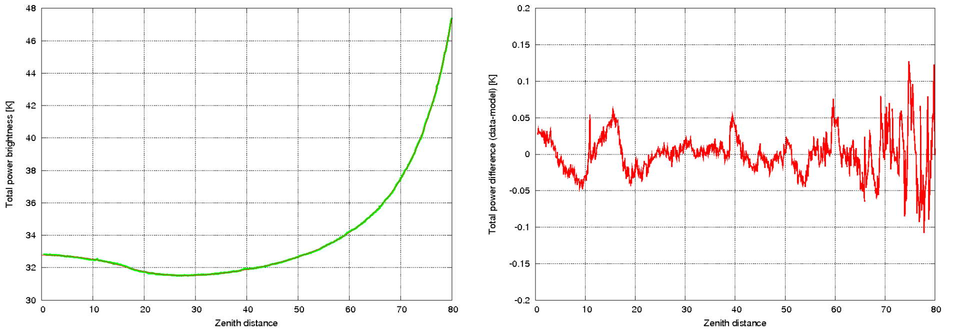

Fig. 1: Original data (green) and model (red) for total power (left), and difference between them (right)

$$\tau(z) = -0.0045 + 1.00672 \sec(z) - 0.002234 \sec^2(z) - 0.0006247 \sec^3(z). \quad (1)$$

Using the transfer equation with this optical depth approximation we get a base line model match that is not satisfactory - the deviations exceed 400 mK at a zenith distance of $> 60^\circ$, therefore we were looking for a better approximation.

Since the entire instrumental profile of the radiotelescope consists of multiple side lobes, the model had to incorporate the radiation coming from the dominant side lobe - this effect is called the spillover effect. Experimentally we found that the best analytic and simple approximation is given by the function:

$$T_{\rm meas} = T_0 + T_1(0.5 + \arctan((a - z)/b)/\pi) + T_2(0.5 + \arctan((c - z)/d)/\pi), \quad (2)$$

where T_0 is a constant shift dominated by system temperature, T_1 is an amplitude of the signal from radiotelescope main beam and T_2 is an amplitude of a spillover (i.e. side lobes looking at the Earth surface, and/or the horizon).

The compliance of measurement data with this model approximation is much better - it gives much smaller deviations than those obtained for the classical model, resulting from the transfer equation. While the traditional model shows a deviations with an amplitude of 400 mK, the amplitude of the deviations for the model proposed by us does not exceed 50 mK. Since the noise temperature amplitude T_0 of the receiving system is similar, we believe that the new model better reproduces the recorded level of radio radiation that interferes a scan across the sky.

This approximation function takes into account the fact that in the recorded signal a significant part of the recorded radiation comes from one dominant side lobe in the directional characteristics of the radio telescope. Of course, we can fine-tune the model by including subsequent side beams, but we must remember that when scanning from zenith to horizon we must avoid strong, extended sources such as the Milky Way.

3 Model for polarized radiation

Since the ToPoS project is dedicated to the measurement of polarized radiation we were also looking for a model describing changes in the background level of the Stokes

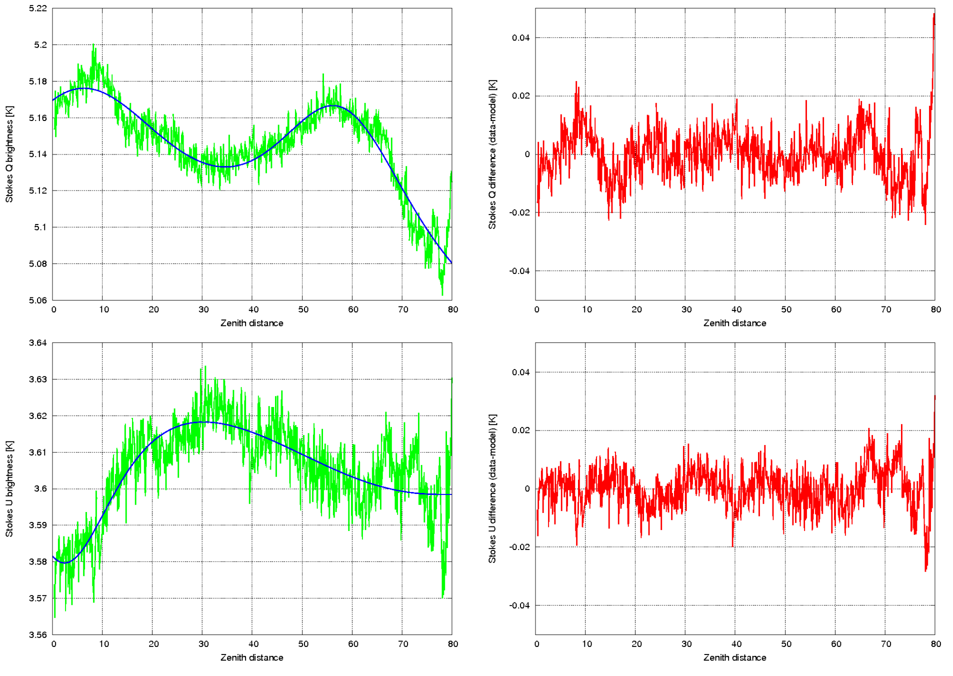

Fig. 2: Original data and model for Stokes Q (upper-left), and difference between them (upper-right), and the same for Stokes U in the lower panels.

parameters (Q & U) caused by the effects described above. We assume that the polarized component is derived from the effects of variations of atmosphere density but also by reflection and scattering on the construction details of radio telescope. This allows us to assume that we can model the $Q(z)$ and $U(z)$ dependencies as a function of the zenith distance using the derivatives of the formula describing the total power, i.e.:

$$Q_{\mathrm{meas}} = Q_0 + Q_1/(1 + [(a_{\mathrm{q}} - z)/b_{\mathrm{q}}]^2) + Q_2/(1 + [(c_{\mathrm{q}} - z)/d_{\mathrm{q}}]^2), \quad (3)$$

$$U_{\mathrm{meas}} = U_0 + U_1/(1 + [(a_{\mathrm{u}} - z)/b_{\mathrm{u}}]^2) + U_2/(1 + [(c_{\mathrm{u}} - z)/d_{\mathrm{u}}]^2). \quad (4)$$

Using this approximation we get a good match to the scans made. The top panels in Figure 2 (left) show the direct results of the Stokes Q measurements from the zenith to the horizon, and the result of the correction using the proposed model is on the right side. The bottom panel shows the results for the Stokes parameter U.

It should be noted that Brouw and Spoelstra (1976) also analyzed and modelled interference in a polarized signal, but used a different model to describe radiation from the environment of the radiotelescopes and wrote nothing about instrumental corrections due to inter-channel leakage and Müller matrix correction.

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