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Absolute Calibration of Polarized Galactic Emission

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Abstract. Absolute calibration of polarization data requires a quite detailed knowledge of many instrumental parameters whose determination is difficult and quite time consuming. In particular, studies of the polarized Galactic emission need absolute calibration. Missing large-scale components in U and Q may increase or decrease the U and Q components of small-scale structures so that polarized intensities and polarization angles are strongly affected in a complex way. This is much more severe than the effect of missing large-scale components in total intensity measurements. We use the absolutely calibrated 21-cm polarization data obtained with the Dwingeloo 25-m telescope to calibrate 21-cm observations made with the Effelsberg 100-m telescope. These in turn serve to calibrate synthesis telescope data. Although the calibration sequence works well, more absolutely calibrated and fully-sampled data with higher sensitivity are needed to match the requirements of present observations. We outline a technique for reaching this goal with moderate effort.

1. Absolute Calibration of the Effelsberg 21-cm Galactic Plane Survey

Absolute calibration of the Effelsberg 21-cm Galactic plane total intensity survey with about $9\overset{'}{.}3$ angular resolution (Kallas & Reich 1980; Reich et al. 1990, 1997) is achieved using the absolutely calibrated Stockert 21-cm survey with $35'$ angular resolution (Reich 1982; Reich & Reich 1986). The Effelsberg survey was observed in Galactic coordinates, which is the most efficient way to use telescope time. Relative baselines were defined by assuming that the emission at the edges of the maps is zero. Convolving the Effelsberg data to the Stockert beam and comparing the two maps revealed the missing emission component of the Effelsberg survey, which was added in a suitable way. The Stockert survey of the entire northern sky was observed by moving the telescope at three fixed elevations for a distance of $80°$ or $140°$ in azimuth. Although a time consuming observing method, its advantage is that it provides the most stable baselines and allows the extraction of the ground radiation contribution to the data. The Stockert maps are then tied to absolutely calibrated sky-horn measurements. The Effelsberg 21-cm total intensity survey is regularly used to account for the missing large-scale structures of the DRAO 21-cm Galactic Plane Survey.

The new Effelsberg 21-cm "Medium Galactic Latitude Survey" aims to cover all accessible latitudes up to about 20°. Linear polarization data are obtained simultaneously with the total intensity data. To minimize the time requirements maps are observed in Galactic coordinates. Typical field sizes are up to 10° or 15° and are scanned both along the latitude and the longitude direction outside of the Galactic plane. For the longitude and the latitude scans linear baselines are subtracted with zero emission defined at both ends. The resulting maps are combined by minimizing the differences introduced by the default baseline setting. When possible, absolute calibration is taken from the absolutely calibrated Dwingeloo polarization data, which has 0°.6 angular resolution (Brouw & Spoelstra 1976). The Dwingeloo survey covers large sections, but not the entire northern sky. This survey consists of measurements from single well-calibrated pointings as described by Brouw & Spoelstra (1976). The data are undersampled – for many areas the position difference between the pointings is several degrees. Maps have been constructed from the ungridded data in U and Q (Uyanıker et al. 1998; Fürst et al. 1999) matching the Effelsberg maps. The difference between the U and Q maps constructed from the Dwingeloo data and the corresponding Effelsberg maps, which were convolved to the same angular resolution, is then added to the Effelsberg map.

These absolutely calibrated U and Q data will be subsequently used to calibrate the polarization data of the DRAO 21-cm survey. Synthesis telescopes normally define the average of U and Q in the field of view as zero.

2. The Need for Absolutely Calibrated Polarization Data

Beck & Hoernes (1996) and Hoernes (1997) have shown the dramatic effect of adding large-scale total intensity and polarization data from the Effelsberg telescope to VLA data for the case of nearby galaxies. Without this combination any analysis of multifrequency synthesis data alone is quite limited or may even be misleading.

Total intensity sources, outside confused regions, can usually be quite well separated from diffuse surroundings, and, except for the uncertainty due to nonlinear gradients in the background emission, a good flux density measurement or other analysis can be made. For a reliable result the intensities of all spatial structures up to the source size must be well represented in the map.

On the other hand, polarization data are observed in Stokes U and Q, which can be positive or negative. The polarized intensity, PI is calculated by: $\mathrm{PI} = (U^2 + Q^2)^{0.5}$ and the polarization angle ϕ from $\phi = 0.5\ \mathrm{atan}(U/Q)$. Looking at the polarized U and Q emission from a discrete extended source with a synthesis telescope often shows more fine-scale structure than is visible in total intensity. Varying Faraday rotation and changes in the magnetic field orientation within the source, or beam depolarization effects, make the U and Q structures more patchy than the total emission, and the fraction of missing flux is usually lower.

The situation, however, is different when looking at Galactic emission structures. While the total intensity emission appears rather smooth at high Galactic latitudes or within the plane towards the anticentre direction, the polarized emission does not. The main reason is Faraday modulation of the intrinsically

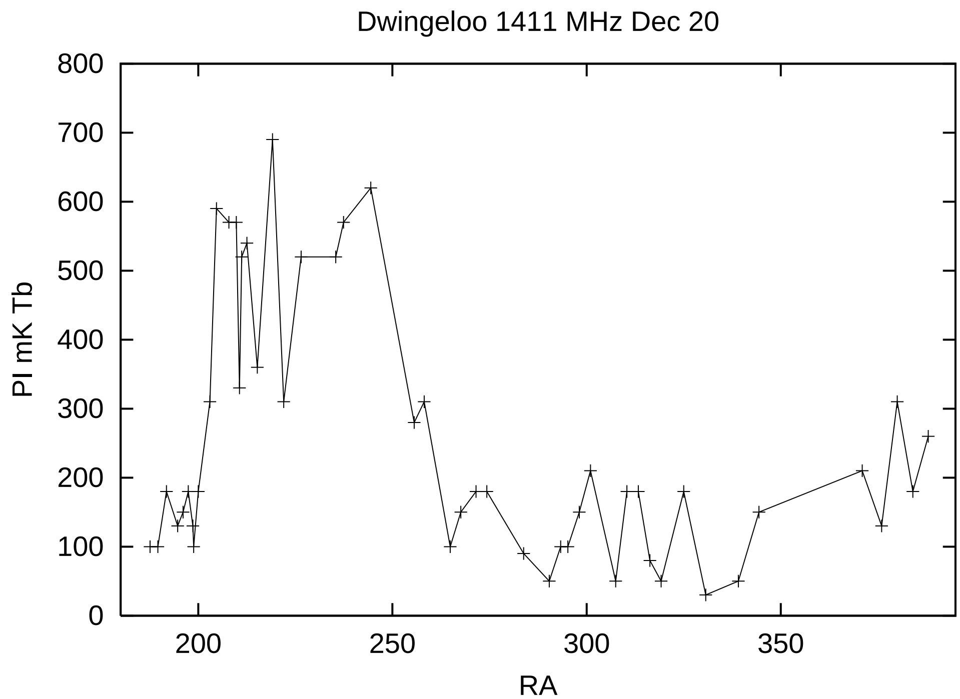

Figure 1. Polarized intensities observed with the Dwingeloo telescope by Brouw & Spoelstra (1976) along right ascension for declination 20°. The individual measurements are shown by crosses.

polarized diffuse background emission by small-scale structures of the interstellar medium (ISM) within the line of sight. Therefore the observed polarized emission is generally not correlated with the total intensity emission, but tells about the properties of the ISM along the line of sight. High-resolution data from synthesis telescopes are required to resolve and to investigate these structures in detail, but absolute calibration of the polarization data are needed.

However, defining the mean of U and Q for the field of view equal to zero is not justified. It is also arbitrary to assume zero emission at the edges of a single-antenna polarization map. These assumptions lead to an incorrect distribution of polarized intensities and polarization angles. One can easily imagine that adding any twisted plane in U and Q to a raw image will drastically change the polarization result on all scales. This holds both for synthesis and single-antenna observations, although the missing components in the latter case generally have larger scales. Variations of the ground radiation components limit the size of maps for single-antenna telescopes, in particular at low elevations.

3. Present Requirements

The Effelsberg 21-cm polarization data have been successfully corrected with the Dwingeloo data in many areas, where the Dwingeloo data are not too sparse and the intensities are sufficiently high. However, in areas where the polarized intensities are below 100 mK, calibration is sometimes not warranted because comparison of convolved Effelsberg maps with the Dwingeloo data indicates some inconsistency. This is not surprising, because the mean errors of the Dwingeloo data are quoted to be about 60 mK (Brouw & Spoelstra 1976). This is much larger than the errors of the Effelsberg measurements, which are about 8 mK at full resolution and considerably lower when convolved to the Dwingeloo resolution. Thus there is a need for more sensitive data, which should ideally be fully sampled in order to eliminate interpolation. We believe this is not a particularly difficult or time consuming project if a 25-m telescope is available. All the difficulties of performing an absolute calibration can be overcome by referring to the Dwingeloo data. In Fig. 1 we show polarized intensity data at declination 20°. Pointing a 25-m telescope at that declination and recording the data for 24 h will give a fully sampled data set, which can be scaled to fit the Dwingeloo scan. Since ground radiation will be constant an absolute calibration will be obtained. Repeating this procedure at declinations separated by a half-beamwidth will give the required set of data.

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