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Measurements of polarized diffuse emission with the SRT

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Abstract. The polarized diffuse emission of our Galaxy provides a unique opportunity to investigate some aspects of Galactic physics. The structure of the Galactic magnetic field can be explored, while structures visible only in polarization, like regions with rapid magnetic field changes, can be investigated only using the polarized emission. In addition, the Galactic synchrotron emission is one of the major contaminants of the Cosmic Microwave Background (CMB) polarization, and its characterization at radio frequencies is fundamental for CMB experiments. While complete mapping of the sky will be soon available at 1.4 GHz, Faraday rotation effects still prevent us from a full analysis of the intrinsic Galactic emission properties. Surveys at higher frequencies are thus desirable, and in particular a large survey at 5-6 GHz can significantly enhance our knowledge of Faraday effects. Mapping the northern sky with the SRT with adequate sensitivity would require about 1000 hours, an affordable project for an SRT-class radiotelescope. Receiver performance requirements are the ones fulfilled by the available technology.

1. Scientific context

The polarized diffuse emission at radio wavelength provides us with information of the physics of the Galaxy. In fact, it allows the study of the properties of the background synchrotron emission in both the Galactic plane and the halo, carrying information on the relativistic electron populations present in these two environments. The structure and the properties of the Galactic magnetic field can also be determined. The radial component can be studied through Faraday rotation measurements, while the tangential component can be investigated via polarization angles of the synchrotron emission. Mapping of the Faraday rotation carries information on the ISM turbulence. Still puzzling are zero emission filaments showing up only in polarization and a multi-frequency approach is recommended to explore their nature. Finally, the Faraday rotation induces variations in the polarization angles, which generates depolarization when integrating along the line of sight. Such polarization tends to cancel out the polarized signal at some distance, introducing a sort of polarization horizon. The higher the frequency, the smaller the Faraday effects and, thus, the farther the polarization horizon: mapping the polarized emission at different frequencies provides us with a sort of tomography, allowing the study of the 3D structure of the magnetized medium.

The study of the diffuse Galactic polarized emission is of great importance also for Cosmic Microwave Background Polarization

(CMBP) investigations. The Galactic synchrotron radiation is expected to be the major contaminant for CMBP experiments up to about 100 GHz and its study at radio frequencies, where it is dominant, allows a clearer view of its contribution. The faint CMBP *B*-mode (crucial to investigate the Inflation era) could be successfully detected only in selected regions with low foreground contamination. Mapping of wide areas (e.g. half or all-sky) helps in identifying clearest sky portions where CMBP observations can be effectively carried out. In addition, a complete view of the foreground synchrotron emission allows us to set the minimum detectable value of this faint, but highly relevant signal. Finally, algorithms to clean the CMBP emission from the astrophysical foreground components greatly benefits from a good knowledge of the contaminant emission properties, like its dependence on both the frequency and angular scale (e.g. see Tegmark et al. 2000). All-sky surveys would help in determining the properties of the Galactic synchrotron emission, not only in a statistical sense, but also locally.

2. Available data

The synchrotron emission can best be observed at low frequency, where it dominates other diffuse components (dust, free-free, and the CMBP itself) and where the signal is strong enough to allow easier detection. To date, the exploration has been mainly done around the Galactic plane and at frequencies lower than 2.7 GHz. The "Southern Galactic Plane Survey" (SGPS, Gaensler et al. 2001) and the "Canadian Galactic Plane Survey" (CGPS, Taylor et al. 2003) are 1-arcmin interferometric surveys aimed at mapping the Galactic plane at 1.4 GHz. These surveys are sensitive only up to the $\sim 30'$ of their primary beams. Larger angular scales will be probed by the single dish project "Effelsberg 1.4 GHz Medium Galactic Latitude Survey" (EMLS, Uyanıker et al. 1999 and Reich et al. 2004). Having a resolution of $10'$, it allows a proper overlap with the interferometric map angular scales. The Galactic plane has also been surveyed at higher frequency by Duncan et al. (1997, 1999). They covered about one half of the plane at 2.4 and 2.7 GHz, with a latitude limit of $|b| < 5°$.

The mid Galactic latitudes have been partially surveyed at 350 MHz by the Westerbork survey (Haverkorn et al. 2003), which mapped the polarized emission in the longitude range $l \sim 140°$–$170°$, up to $b = 30°$.

High-latitude regions are not studied as much, although most recent surveys are starting to fill this gap. In fact, apart from sparse observations at all Galactic latitudes made in the 1960s and 1970s (e.g. Brouw & Spoelstra 1976, who collected data at 5 frequencies between 408 and 1411 MHz), the entire northern and southern sky are now being mapped at 1.4-GHz by Wolleben et al. (2004) and Testori et al. (2004), respectively (e.g. see Fig. 1).

These surveys are sensitive to large angular scale structures of the polarized emission in interesting (for CMBP purposes) low emission regions. However, their poor angular resolution (larger than $30'$) and sensitivity (about 15 mK) do not allow the analysis of the faint areas required by sub-degree CMBP experiments, which would require better resolution (5-$10'$) and sensitivity (rms signal about 5-10 mK, see Bernardi et al. 2003 and Carretti et al. 2005c). In addition, Faraday rotation can strongly modify the polarized emission pattern at low frequency. In fact, Carretti et al. (2005a) found that it can introduce a randomization of polarization angles, which, transferring power from large to small angular scales, can cancel out the large-scale structure of the polarized emission. These authors found that this effectively occurs at 1.4 GHz for Galactic latitudes $|b| < 40°$–$50°$, making hard to infer both the Galaxy structure and the CMBP contamination. Observations at higher frequencies are thus necessary to properly trace the intrinsic diffuse polarized emission of the Galaxy.

3. A 5-6 GHz survey

High Galactic latitude observations with proper sensitivity, resolution, and frequency are just at the beginning. Only a couple of areas of a few square degrees each have been ob-

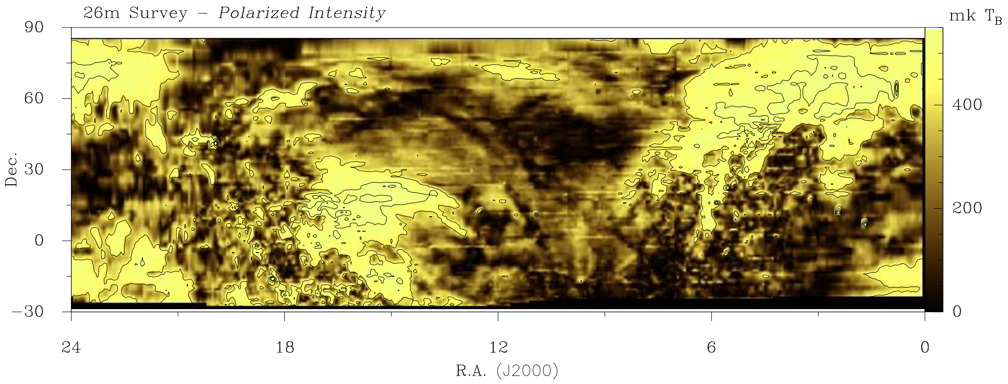

Fig. 1. Map of the 1.4 GHz polarized emission of the northern Celestial hemisphere (from Wolleben et al. 2004).

served to date at 1.4 and 2.3 GHz, without significant Faraday effects (Bernardi et al. 2003; Carretti et al. 2005b,c).

In the very near future, a significant improvement is expected from two forthcoming surveys: the 2.3 GHz "Parkes Galactic Meridian Survey" (PGMS) and the 5 GHz "Medicina Galactic Meridian Survey" (MGMS). They will image the Galactic emission along Galactic meridians at frequencies higher than 1.4 GHz and are aimed at studying the latitude dependence.

However, a significant enhancement of our knowledge can be achieved through an all-sky survey at 5-6 GHz. Such a survey, in combination with the existing 1.4 GHz surveys, would allow the study of both the Galactic structure and its magnetic field without significant modifications by Faraday rotation. In addition, mapping half of the sky, it would allow one not only to obtain a good knowledge of the statistical properties of the synchrotron emission, but also the determination of the local properties. This would provide a reliable template of the contamination of the CMB, significantly improving the effectiveness of cleaning algorithms.

Considering the sensitivity of the 1.4 GHz surveys and assuming a synchrotron spectral

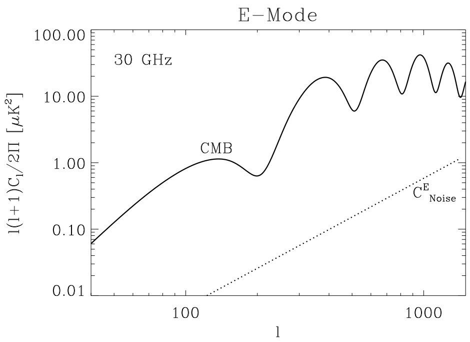

Fig. 2. E-mode noise power spectrum $C^E_{\rm noise}$ of the proposed survey extrapolated to 30 GHz, the lower edge of the cosmological frequency window for the E-mode signal. The E-mode spectrum expected for the CMBP is reported for comparison. The noise level, well below that of the CMBP, shows that the survey will ensure a safe monitoring of the synchrotron contamination when potentially disturbing the cosmic signal.

slope of −2.8 (Platania et al. 1998), a sensitivity of 0.5 mK for 4′ FWHM pixels is estimated to ensure a proper study of the Galactic emission structure. This sensitivity limit seems also adequate for CMBP purposes. In fact, the noise power spectrum extrapolated to 30 GHz (the lower edge of the cosmological frequency

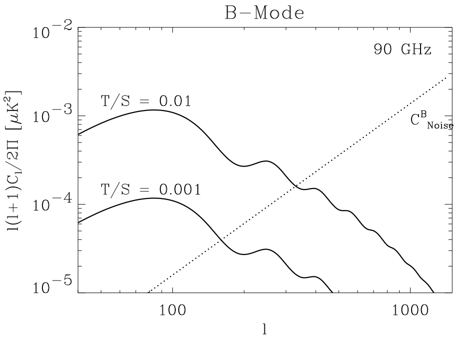

Fig. 3. B-mode noise power spectrum $C^B_{\rm noise}$ of the proposed survey extrapolated to 90 GHz, close to the frequency minimizing the Galactic contributions. Models with tensor-to-scalar perturbation power ratio of $T/S = 0.01$ and 0.001 are shown for comparison.

window for the E-mode signal) permits the detection of the Galactic components if strong enough to pollute the cosmic signal (Fig. 2).

Recent results in low emission areas also show that the synchrotron emission competes with the B-mode of the cosmic signal for models with tensor-to-scalar perturbation power ratio $T/S \sim 0.01$ (Carretti et al. 2005b,c). Also for such a component, the noise limit of the proposed survey is expected to allow the monitoring of the contamination (Fig. 3).

Finally, a number of technical requirements, other than sensitivity, have to be accounted for, to carry out such a project. They can be summarized as follows:

- **Polarimetric backend**. A correlation polarimeter is needed to minimize $1/f$-noise effects. The correlation of the Right- and Left-Handed circular polarizations is necessary to simultaneously measure both the Stokes parameters Q and U;
- **Sensitivity**. For a receiver with $T_{\rm sys} = 20$ K and 1.0-GHz bandwidth, a 1-second sensitivity of $\sigma_{\rm 1s} = 0.45$ mKs$^{1/2}$ is achievable;
- **Instrumental polarization**. On-axis instrumental polarization should be less than 1%, i.e. the orthomode transducer needs both isolation and cross-talk between ports of the order of 40 dB; Off-axis instrumental polarization should be less than 1%. This is achievable if the antenna (optics and feed horn) has a cross-polarization pattern better than 35 dB;
- **Scanning capabilities**. With a single-dish antenna, maps are made by scanning the sky in orthogonal directions. This requires having software and hardware that allow precise antenna pointing during the scans (10″–20″). The polarimeter should also acquire the data at an appropriate rate: considering a sampling better than three pixels per beam, a 3′.9 FWHM beam size at 5 GHz, and an antenna speed of 400″/s, the proper sampling rate frequency would be $\nu > 10$ Hz (both such speed and sampling rate are presently operative at the Medicina radiotelescope).
- **Data Reduction Software**. Maps of both diffuse emission and discrete sources require calibration and map-making softwares. Those currently used at the Medicina radiotelescope would be satisfactory also for the SRT.

All these technical details, close to the state-of-the-art technology, are achievable (if not already achieved) at the polarimetric facility of the Medicina radiotelescope. This makes such a project with a telescope like the SRT feasible.

Assuming the values above, full mapping of half of the northern sky (2π sr) can be carried out in about 1000 h. This is the size of typical large survey projects and can be carried out in 2–3 years, by allocating 2-3 weeks of observing time per year.

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