SF2A 2016
C. Reylé, J. Richard, L. Cambrésy, M. Deleuil, E. Pécontal, L. Tresse and I. Vauglin (eds)

MAPPING THE RADIO SKY FROM 0.1 TO 100 MHZ WITH NOIRE

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Abstract. The goal of the NOIRE study (Nanosats pour un Observatoire Interférométrique Radio dans l'Espace) is to assess the scientific interest and technical feasibility of a space borne radio interferometer operating from a few kHz to a few 10 MHz. Such observatory would be able to build a global sky map with an unprecedented spatial resolution depending on the selected technical implementation. We present a review of our understanding of the Galactic mapping, assessing the instrument requirement for such observations.

Keywords: Radioastronomy, Interferometry, Space, Nanosatellites, Galaxy

1 Introduction

The radio sky at the low frequencies is bright. Its brightness temperature peaks at about 1 MHz with a value of 10^7 K. The source of this radiation is the free-free synchrotron radiation of electron spiraling in the Galactic magnetic field (de Oliveira-Costa et al. 2008, and references therein). Hence the mapping of the low frequency radio sky is not only a science objective by itself, but also a crucial input for foreground radio sources observations (e.g., radio sources in the Solar System), as well as faint background sources (Dulk et al. 2001). The current space borne low frequency radio instruments such as those onboard Cassini (Gurnett et al. 2004) or STEREO (Bougeret et al. 2008) space mission have been calibrated using a model of the Galactic background emission (Zarka et al. 2004; Zaslavsky et al. 2011).

Mapping the sky is the first step for any observatory that opens an unexplored spectral band. For instance, the LOFAR (Low Frequency Array, van Haarlem et al. (2013)) team recently published its MSSS (Multifrequency Snapshot Sky Survey) (Heald et al. 2015), which covers the whole Northern sky from 30 to 160 MHz with an angular resolution ≤ 100 arcsec. NOIRE (Nanosats pour un Observatoire Interférométrique Radio dans l'Espace) is a feasibility study for a radio interferometer similar to LOFAR, but in space and covering the 0.1 to 100 MHz spectral band. A dedicated paper presents this study in this volume (Cecconi et al. 2016). It is lead by the French space agency CNES (Centre National d'Études Spatiales) and is assessing the possibility to use nanosatellites. The nanosatellite concept is a promising platform for distributed instrumentation. However due to the limitation of power resources, the feasibility assessment is not straightforward. Careful evaluation of science objectives linked with instrument and platform requirements are thus necessary.

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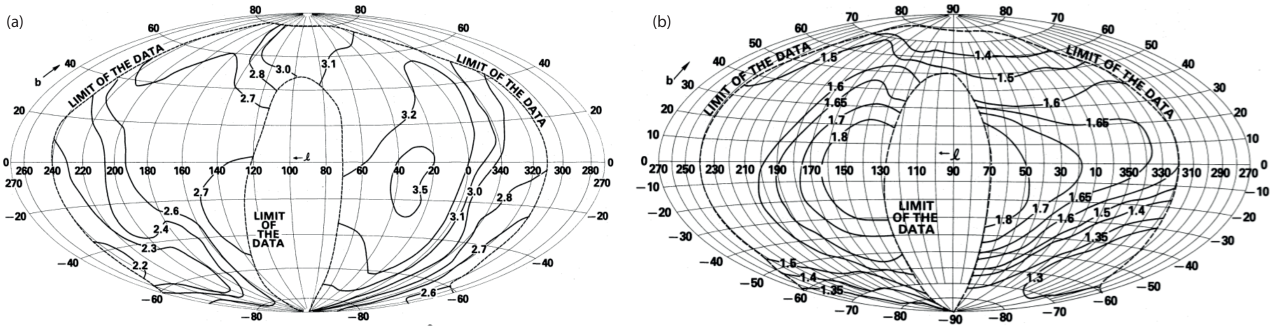

Fig. 1. Coutour map in galactic coordinates of the nonthermal emission as published by Novaco & Brown (1978). Panels (a) and (b) are showing maps at 3.93 and 1.31 MHz respectively. The contours are in units of 10^6 and 10^7 K, respectively.

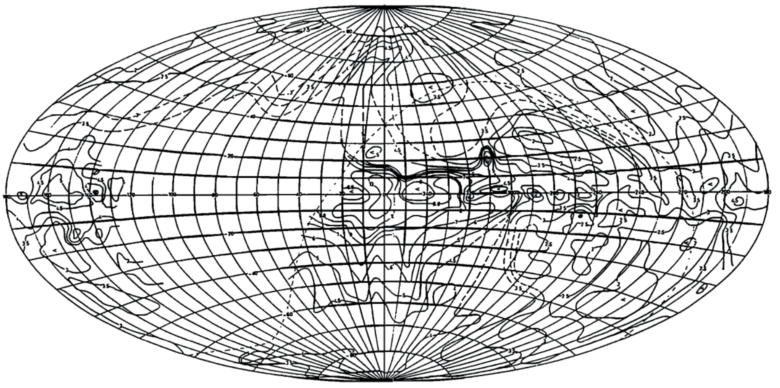

Fig. 2. A 10 MHz map of the galaxy based upon data from several surveys that were convolved to a common anluar resolution of 5°. Contours are in units of 8×10^4 K. Figure extracted from Cane & Erickson (2001).

2 Review of known galactic background characteristics

The first map of the Galaxy is published by Novaco & Brown (1978). They have built maps and spectra from 1 to 10 MHz using RAE-2 (Radio Astronomy Explorer 2) data (Alexander et al. 1975). Figure 1 is showing the sky maps at 3.93 and 1.31 MHz. However it is very difficult to use these maps for calibration of low frequency radio instruments since: (i) the RAE-2 data are not readily available (NSSDC is holding microfilms and tapes[*], but no digitized version is available); (ii) the maps are not complete, as shown on Fig. 1; and finally (iii) the Novaco & Brown (1978) paper is not explaining the methodology used to derive the radio maps. Cane & Erickson (2001) are providing a combined map at 10 MHz, see Fig. 2. This map has a better coverage and resolution than that of Novaco & Brown (1978) at 10 MHz, but it is still not complete. A complete map at 30 MHz has been published by Cane (1978). For higher frequencies, Guzmán et al. (2010) is proposing a map at 45 MHz, which is reproduced on Fig. 3. This paper is also providing a map of spectral indices from 45 to 408 MHz. In the recent years, Global Sky Models have been developed and improved but their spatial coverage is still scarce below 100 MHz (de Oliveira-Costa et al. 2008; Zheng et al. 2016), although the MSSS is filling the gap down to 30 MHz in the Northern hemisphere.

The integrated spectrum of the galatic radiation has also been published Cane (1979); Dulk et al. (2001); Manning & Dulk (2001). Figure 4 is showing a compilation of published spectra and an measure of galactic background anisotropy from WIND/Waves data (Manning & Dulk 2001).

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[*] `http://nssdc.gsfc.nasa.gov/nmc/datasetSearch.do?spacecraft=RAE-B`

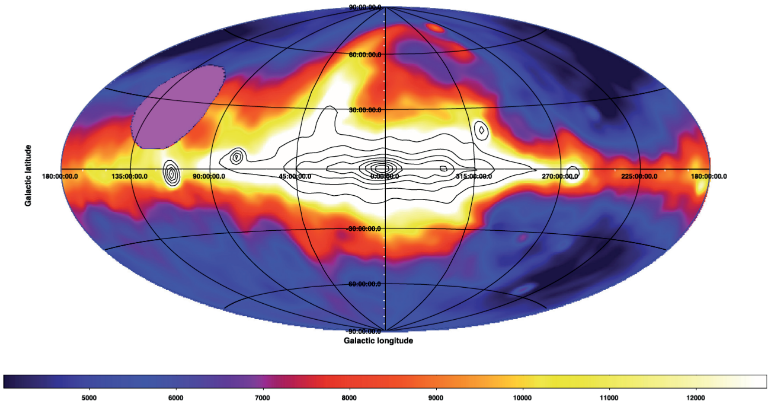

Fig. 3. Hammer-Aitoff projection of the 45 MHz full sky map. Eight contours are drawn between 15 000 and 60 000 K. The map does not cover the $\delta > +65°$ zone. Figure extracted from Guzmán et al. (2010).

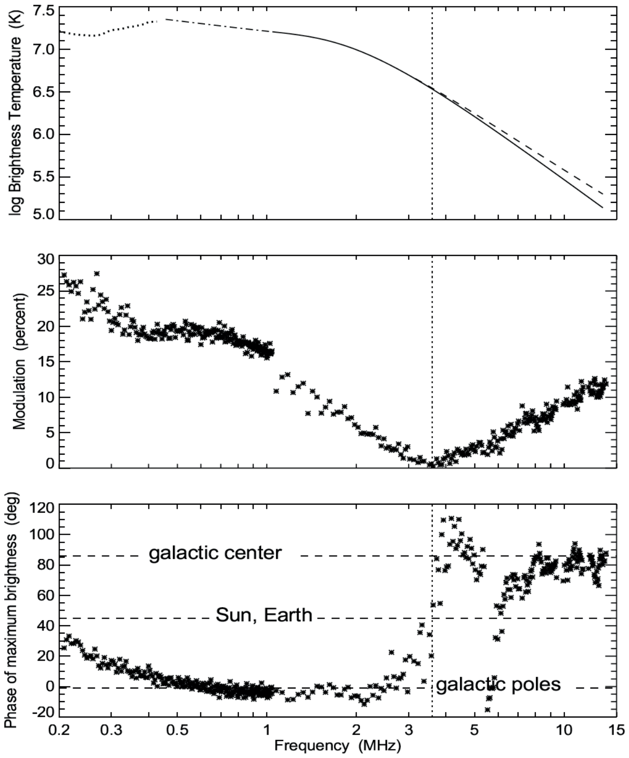

Fig. 4. Top panel: Estimated spectrum of brightness temperature of the Galactic background radiation obtained from sources described in the text. Middle panel: Wind/WAVES measurements of the degree of modulation (peak minus average power) of the signal from the Galactic background. The measurement uncertainty is evident from the variation from one frequency to another. Bottom panel: Spin phase of maximum intensity. The ordinate is ecliptic longitude, with an ambiguity of 180° inherent in reception by a dipole antenna. Figure extracted from Manning & Dulk (2001).

3 Requirements for NOIRE

The performance requirements shall be defined for the spectral, temporal, spatial scales, as well as for the signal amplitude and fluctuations (sensitivity and dynamical range) and for the polarization degrees. Figure 4 provides preliminary spectral performance requirements. The lowest observable frequencies, above the local background is about 100 to 300 kHz (see also Figs. 1 and 2 of Zarka et al. (2012)). In order to correctly sample the peak of the emission, the frequency resolution should be set to 100 kHz below 5 MHz. At higher frequencies, a 1 MHz sampling resolution is sufficient up to 100 MHz. Considering the temporal scale, as we want to build a static map, the longer integration times the better signal to noise ratio. The aimed spatial scales are of the order of 1° or better. The observed signal is reaching 10^7 Jy at 3 MHz. The fluctuations on spatial scales still remain to be evaluated. As far as polarization is concerned, no significant component is expected due to Faraday rotation depolarization in the interstellar medium.

The previous statements can be turned into instrumental, platform and system requirements. The temporal, spectral, sensitivity and dynamical range performances directly relates to the radio receiver design. The performance requirements drafted here are fully compatible with current space radio receivers. The spatial resolution is proportional to the λ/B ratio, where λ is the wavelength and B the interferometric baseline. With a 100 km baseline, the reachable spatial resolutions are 20.6 arcsec, 1 arcmin and 10.3 arcmin at 30, 10 and 1 MHz, respectively.

The interferometer could work as a full sky imager using the 3D interferometry inversion (Carozzi 2015) or in a beam-forming mode, as done for the LOFAR/MSSS.

Although the measurement, system and platform requirements presented here are not strongly driving the design of NOIRE, it is noticealbe as other science objectives are putting more stringent constraints on each of the addressed parameters.

4 Conclusions

This work is still under development, and a support from an experienced team in galactic background modeling and observations would be very helpful. This support would help the NOIRE team to assess the constraints drafted in this paper, and would be very welcome for the science analysis when data are available. However, considering this preliminary assessment, the NOIRE concept would provide a suitable observation platform for this science objective.

The NOIRE team acknowledges support from the PASO (Plateau d'Architecture des Systèmes Orbitaux) team at CNES. The NOIRE team members also acknowledge support from their institutions (Centre National de la Recherche Scientifique (CNRS) Observatoire de Paris, Univ. Paris 7 Denis Diderot, Univ. de Montpellier, Commissariat l'Energie Atomique (CEA), ONERA, Univ. Paul Sabatier, Univ. d'Orléans and Telecom Paris Tech) as well as their associated space campuses (Centre Spatial Universitaire de Montpellier-Nîmes, Univ. de Montpellier; Fondation Van Allen, Institut d'Electronique du Sud, Univ. de Montpellier; Campus Spatial Diderot, UnivEarthS, Sorbonne Paris Cité; and C2ERES, ESEP/PSL). They also thank the Dutch OLFAR teams (ASTRON, Radboud Univ. Nijmegen, TU Twente and TU Delft) for fertilizing discussions.

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