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LFmap: A Low Frequency Sky Map Generating Program

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ABSTRACT

A C program has been developed to generate maps of the sky from tens to hundreds of MHz. The method of calculation is described as well as instructions for running the program.

1. Introduction

Maps of the sky in the operating range of the LWA are useful and necessary for LWA development. Maps can be used for comparison with observations made with prototype instruments and for calculating the diurnal variation of sky noise from single antennas to compare with measurements. Many maps have been published below 100 MHz but most of these are not in electronic format. These maps are also at a few select frequencies while maps at any frequency in the LWA band are needed. LFmap is a program written in the C language to provide such maps.

At low frequencies the brightness temperature of the sky is a power law:

$$T_{sky} \propto \nu^{-\beta}$$

The temperature spectral index β is known to be large in regions of low T_{sky} and vice versa. This is interpreted as T_{sky} being a superposition of an isotropic component with a steep spectrum and an anisotropic component with a generally flatter spectrum. The cosmic microwave background (CMB) is isotropic but has a flat spectrum and is too cool to account for all the isotropic emission. The anisotropic component is due to synchrotron radiation from cosmic ray electrons in the Galactic magnetic field. Thus the brightness temperature at frequency ν in direction α,δ can be written:

$$T_{sky}(\nu, \alpha, \delta) = T_{CMB} + T_{Iso}(\nu) + T_{Gal}(\nu, \alpha, \delta)$$

T_{CMB} is the 2.73K cosmic microwave background. T_{Iso} is the isotropic component and only dependent on frequency. T_{Iso} is usually attributed to the integrated emission of unresolved extragalactic radio sources but T_{Iso} could be an isotropic component of Galactic emission, or a combination of both. Cane (1979) has presented a 2-disk model of the Galaxy that accounts for much of the observed emission but obtain a better fit with an extragalactic component. Keshet et al. (2004) present a model of Galactic emission that accounts for all of the observed emission with no extragalactic component.

Section 2 describes how LFmap calculates T_{Iso} and T_{Gal}. Section 3 describes how to run LFmap. Section 4 discuses some of the limitations of LFmap. Section 5 gives a brief summary.

2. Calculating T_{Iso} and T_{Gal}

Lawson et al. (1987) use source count data from surveys at 610 and 1415 MHz to estimate the extragalactic background from unresolved sources. They adopt an upper bound of 50 K at 150 MHz and a spectral index of 2.75. LFmap uses these values to calculate the isotropic contribution from extragalactic sources at any frequency:

$$T_{EG}(\nu) = 50\ \mathrm{K} \left(\frac{150\ \mathrm{MHz}}{\nu}\right)^{2.75}$$

LFmap uses T_{EG} for T_{Iso}. This does not include any Galactic contribution to T_{Iso} but is consistent with the calculation of T_{Gal} described below.

In the absence of spectral bending T_{Gal} at any frequency can be calculated from knowledge of the temperature and index at a known frequency ν_o:

$$T_{Gal}(\nu, \alpha, \delta) = T_{Gal}(\nu_o, \alpha, \delta) \left(\frac{\nu_o}{\nu}\right)^{\beta}$$

Haslam et al. (1982) published an all sky map at 408 MHz. Platania et al. (2003) performed a detailed analysis of the Haslam map revealing many "stripes", spurious features in the measurements introduced by the scanning techniques. Platania et al. also destriped the 1420 MHz map (Reich 1982; Reich & Reich 1986) of the northern hemisphere and the 2326 MHz map (Jonas et al. 1998) of the southern hemisphere. After subtracting the CMB and the unresolved extragalactic background (Lawson et al. 1987, see above) from each map, convolving to the Haslam map resolution and performing a detailed analysis of error effects in the overlap region, they derived spectral indices for Galactic emission.

LFmap uses Platania's destriped Haslam map (Figure 1) and their spectral index map that included systematic and statistical errors in the construction. The spectral index map is incomplete for declinations less than -79.6°. LFmap scales all pixels in this region with an index of 2.695, the average index of the rest of the map.

2.1. Spectral Bending & HII Absorption

If the Galactic emission had a constant spectral index from 20 to 2326 MHz the index map of Platania et al. would be sufficient. However there is a bend in the spectrum with a large change near 200 MHz (e.g. Purton 1966, Bridle 1967, Howell 1970, Lawson et al. 1987) with steeper indices at higher frequencies and shallower at lower, see Figure 2. This is due to the flattening of the Galactic electron spectrum below energies ≈ 3 GeV (Boezio et al. 2000).

Spectral bending can be dealt with by scaling the 408 MHz map with the Platania indices to an intermediate frequency near 200 MHz then calculating new indices by using a lower frequency map. The 22 MHz map of the northern sky (Roger et al. 1999) is used for this purpose after precessing to J2000.0 epoch and resampling on the 408 MHz grid. There are some caveats however. The 22 MHz map is incomplete for declinations $> 75°$ and $< -27°$ as well as regions around strong discrete sources (Cygnus A, Virgo A, and Taurus A). The 22 MHz map also shows strong free-free absorption from ionized Hydrogen (HII) in regions along the Galactic plane. This creates a further complication since HII absorption does not become important until much lower frequencies than the bend in spectrum. HII absorption is discussed extensively in Cane (1977) where, above 20 MHz, HII absorption is most prevalent in an area $< 10°$ in Galactic latitude and $40 - 60°$ in Galactic longitude near the Galactic center. In Cane (1977) absorption begins to be seen around 80 MHz but it is only around 40-50 MHz that absorption becomes appreciable, and quickly becomes strong at lower frequencies. This is consistent with the 45 MHz maps of Alvarez et al. (1997) where the effects of absorption are not apparent.

LFmap deals with spectral bending by scaling the destriped 408 MHz map with the high frequency indices to a user specified intermediate frequency. Where the 22 MHz map overlaps the scaled map, the scaled map is convolved to the 22 MHz resolution and new spectral indices calculated. Indices for incomplete regions around strong discrete sources are set to the average index of the surrounding areas. Indices in the other incomplete regions are set by breaking the complete regions into 3 classes: Galactic center (GC) and Bulge regions, minimum and cool regions, and other Galactic emission regions. The average index in each class is calculated. The incomplete regions are divided into the same classes and assigned the average index for the corresponding class (see Figures 3 and 4).

LFmap handles HII absorption by setting the indices in the region affected by HII absorption to the average index for the GC/Bulge class. The user sets a parameter determining at what frequency HII absorption should be considered. The map is scaled from the spectral bend frequency to the absorption frequency then new spectral indices for the HII region are calculated from the 22 MHz map. The map is then scaled to the final frequency.

2.2. Discrete Sources

The spectral indices and scaling calculations described above generally give unreliable brightness temperatures for discrete sources. The two brightest discrete sources are Cas A and Cyg A. LFmap attempts to correct these sources by replacing their pixels with temperatures corresponding to their measured fluxes at 74 MHz and scaling with an index of 2.77 for Cas A and 2.66 for Cyg A (Whitfield 1957). LFmap makes no attempt to correct other discrete sources.

3. Running LFmap

Before running LFmap the user must first set parameters in the "LFmap.config" file. These parameters are:

FINALFREQ - the desired frequency (in MHz) of the final map.

BENDFREQ - the intermediate frequency (MHz) to which the 408 MHz map should be scaled with Platania's indices before calculating new indices with the 22 MHz map.

ABSFREQ - frequency (MHz) below which HII absorption should be taken into account.

OUTFORM - format of the output file. The choices are:

1 – ASCII .txt file in equatorial coordinates in a 3 column format giving the RA and DEC (in degrees) of each pixel center and the brightness temperature (in Kelvin).

2 – ASCII .txt file in Galactic coordinates in a 3 columns format giving the Galactic longitude and latitude (degrees) of each pixel center and the brightness temperature (Kelvin). Note in these coordinates the data is irregularly gridded.

3 – FITS file in equatorial coordinates and plate carrée projection

4 – FITS file in equatorial coordinates and plate carrée projection but without '-CAR' in the CTYPE keywords. This is necessary for some FITS viewers (e.g. AIPS) that do not recognize the plate carrée designation.

If desired the user can scale to the final frequency using just Platania's indices by setting BENDFREQ $<$ FINALFREQ. The user can also leave out the effects of HII absorption by setting ABSFREQ $<$ FINALFREQ.

4. Discussion

LFmap attempts to construct low frequency sky maps taking into account effects such as spectral bending and HII absorption but the program does have deficiencies. The incompleteness of the 22 MHz map below declinations -27° means important HII regions near the Galactic center are unsampled. For locations in New Mexico this region of the sky is limited to elevations less than 30°, however this is a bright region of the map and any absorption unaccounted for could have a big effect on calculations of antenna temperature, for example. At the high frequency end of the LWA band where HII absorption is low, effects of unaccounted absorption in this area are probably minimal.

Another deficiency is the treatment of discrete sources. Discrete sources don't necessarily have the same spectral index as Galactic emission and may have low-frequency cut-offs due to absorption. Even the spectra of Cas A and Cyg A, the only discrete sources treated individually in the program, turnover around 30 MHz (Whitfield 1957) and LFmap does not take this into account.

5. Summary

LFmap is a C program to produce maps of the sky in the frequency band of the LWA. The program scales the 408 MHz all-sky map of Haslam et al. (1982) to lower frequencies taking into account 3 components to the emission: the CMB, isotropic emission from unresolved extragalactic sources, and anisotropic Galactic emission. The 22 MHz map of Roger et al. (1999) is used to deal with the flattening of the Galactic spectrum below about 200 MHz and the effects of HII absorption regions below about 45 MHz. Corrections are made to the discrete sources Cas A and Cyg A but no corrections are made to other discrete sources. The final map can be output as a plate carrée projection in text or FITS format.

6. Acknowledgments

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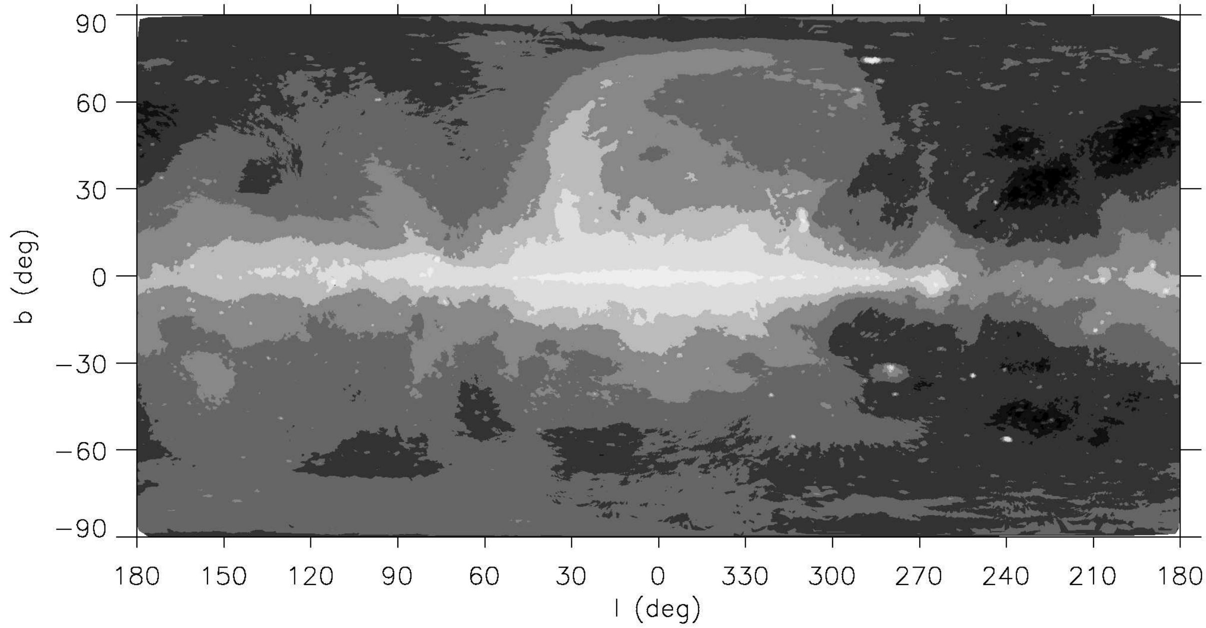

Fig. 1.— The 408 MHz map of Haslam et al. (1982) after destriping (Platania et al. 2003), presented in Galactic coordinates.

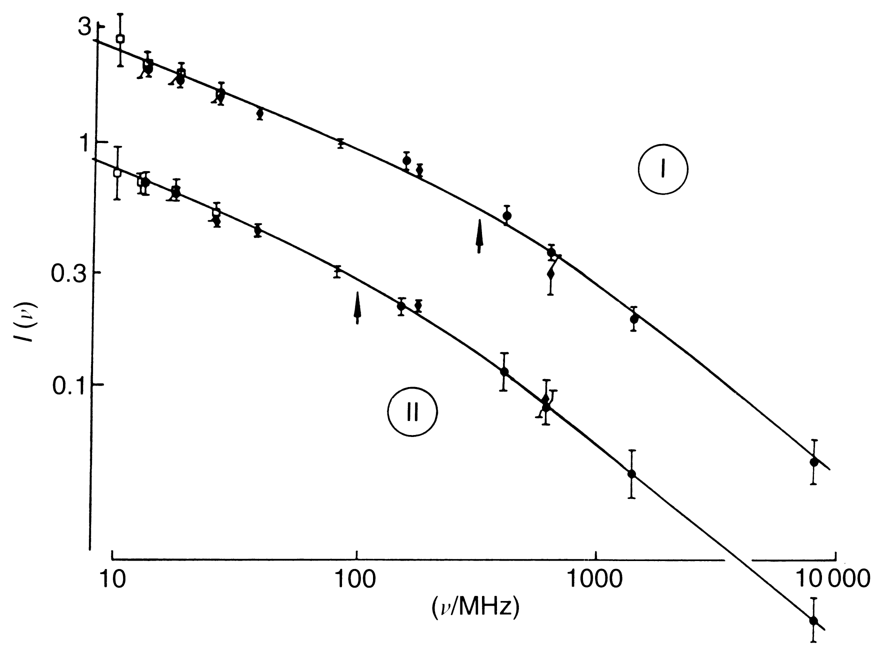

Fig. 2.— Spectral bending of Galactic emission near 200 MHz (From Longair (1994)). Region I corresponds to the "spiral arm" and region II to the "interarm" regions of Bridle (1967).

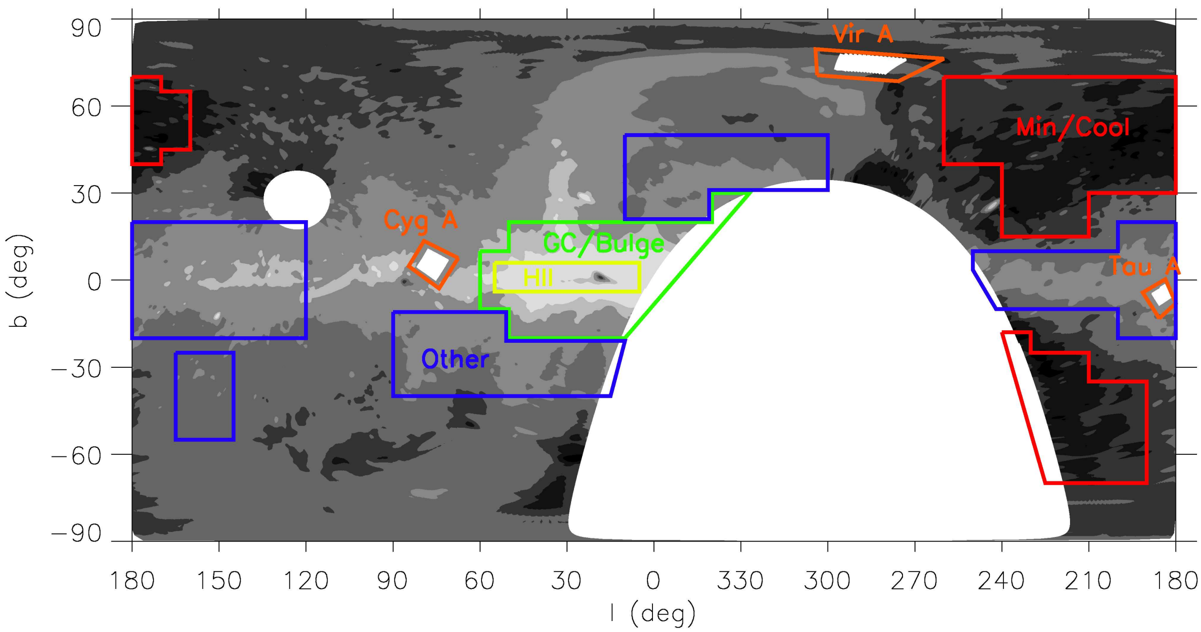

Fig. 3.— The 22 MHz map of Roger et al. (1999) is divided into classes: green = GC/Bulge, red = minimum/cool emission, blue = other Galactic emission. The average index for the complete area of the map in each class is calculated. These indices are used to fill the incomplete regions of the map (see Figure 4). The yellow box shows an area affected by HII absorption and is not included in the GC/Bulge class calculation. Indices for incomplete regions around the strong discrete sources Cyg A, Vir A, and Tau A, are set to the average index of the complete regions inside the orange boxes.

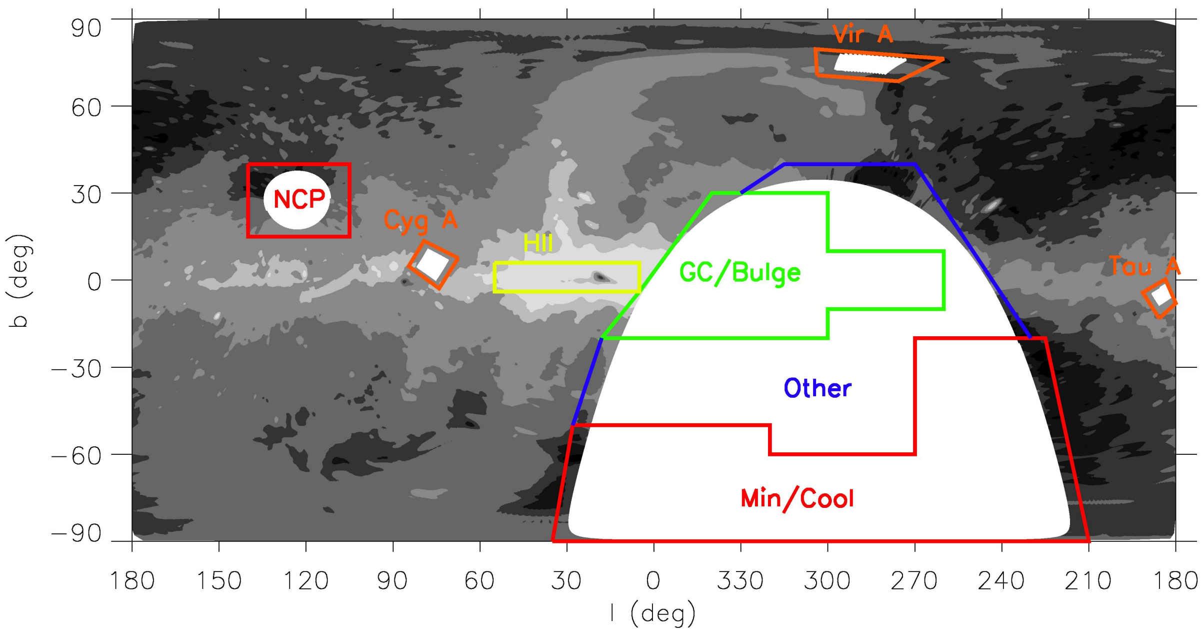

Fig. 4.— The incomplete regions are divided into classes and the spectral indices in each region set to the average index from the classes of Figure 3. The yellow box is a region affected by HII absorption, indices in this area are set to the value for the GC/Bulge class. The frequency at which indices are calculated for the absorption region is a user controlled parameter. The incomplete region around North Celestial Pole (NCP) is scaled with the average index of the min/cool class. Incomplete regions around strong discrete sources are labeled and scaled with the average index of the surrounding regions.