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CONVERSION OF ECP MAPS INTO HEALPIX MAPS

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We describe a method developed to convert the cartesian all-sky map at 1420 MHz into Healpix, the format conventionally adopted in the experiments dedicated to Cosmic Microwave Background anisotropies. We checked the reliability of the elaborated recipy by successfully performing a forward and backward transformation between the two pixelization schemes, confirming that no informations have been lost in the reprojection of the data at the relevant scales ($\theta \gtrsim \theta_{HPBW}$). The implemented algorithm has been exploited to project the 408 MHz map and the DRAO 1420 MHz polarization map into Healpix as well. The mentioned surveys are relevant not only for evaluating the impact of the Galactic diffuse synchrotron emission on CMB anisotropies measurements, but also for investigating its statistical properties in the context of the foreground separation problem.

1 Introduction

In the perspective of the CMB dedicated space missions WMAP[1] (ongoing) and Planck[2] (planned for next year), the angular power spectrum[3] analysis has been extended to the foregrounds expected to contamine the cosmological signal. With regard to the Galactic synchrotron radiation, dominant over the other diffuse components (Bremsstrahlung and thermal and non-thermal dust emission) at about 1 GHz, the map providing the deepest insights into its statistical properties (because characterized by good sensitivity and complete coverage) is the full-sky total intensity map at 1420 MHz (Reich 1982 ; Reich & Reich 1986; Reich et al. 2001). The original map (partially[4] available for donwloading at the homepage of the radio-continuum group of the MPIfR-Bonn[5]) is provided to the scientific community in different projection, for example as equidistant cylindrical (ecp) map. To render this map 1) directly comparable with the ones produced by satellites, 2) analyzable with the software prepared for the angular power spectrum computation and 3) suitable for component separation applications, we have projected it into HEALPIX (Gorski et al. 2005), the pixelization scheme adopted by the WMAP and Planck consortia.

2 The pixelization schemes

2.1 Equidistant Cylindrical Pixelization

The NOD2 library for astronomical routines, originally written at Jodrell Bank for the analysis of continuum surveys, has been widely developed at the MPIfR of Bonn (see Haslam 1974) for the treatment of the Effelsberg telescope data. In the basic NOD2 document the time ordered data are arranged in a tabular form and packed into a one-dimensional array along with an identifying title and associated observational parameters. Programs are available for converting the NOD2 format into the standard fits format and vice versa.

The map we produced at 1420 MHz with the NOD2 package is in ecp format. An ecp map is ideally constructed wrapping a cylinder around the sphere and projecting its details onto the cylindrical surface. Then, the cylinder is unwrapped into a flat surface, yielding a rectangular-shaped map in which the size of the polar regions is largely exaggerated.

2.2 HEALPIX

HEALPIX (acronymous of Hierarchical Equal Area isoLatitude Pixelization) is the curvilinear partition of the sphere optimized for fast spherical harmonics transforms and angular power spectrum estimation. The picture elements have equal area, but vary in shape depending on their position. The basic configuration constitutes of 12 pixels organized in three rings around the equator and the poles (see Fig. 1, taken from Gorski et al. 2005).

To increase the number of pixels in the map the sides of these 12 pixels are divided in $n_{side} = 2^n$ parts, so that the total number of pixels on the sphere is given by $12 \times n_{side}^2$ (n_{side} is called resolution parameter). All pixel centers lay on rings of constant latitude and are equidistant in azimut. The equatorial isolatitude rings (characterized by $|\cos\theta| < 2/3$, where θ is the colatitude) are divided in the same number of pixels. On the contrary the isolatitude rings located within the polar regions ($|\cos\theta| > 2/3$) contain a number of pixels varying with the distance from the poles (namely diminishing of one unit per quadrant from a ring to the succeeding one going toward the pole).

3 From ecp to HEALPIX

In an ecp projection of the sphere lines of constant latitude and of constant longitude intersect at right angles at fix intervals ($\Delta\phi \sim \Delta\theta$, where ϕ and θ are respectively longitude and colatitude), so defining the pixels of the map. The number of pixels is therefore the same at all latitudes. On the contrary in

[1]http://lambda.gsfc.nasa.gov/product/map/

[2]http://www.rssd.esa.int/planck

[3]The angular power spectrum is the statistical estimator commonly used by cosmologists to study the CMB fluctuations field.

[4]So far the northern celestial hemisphere has been released.

[5]http://www.mpifr-bonn.mpg.de/survey.html

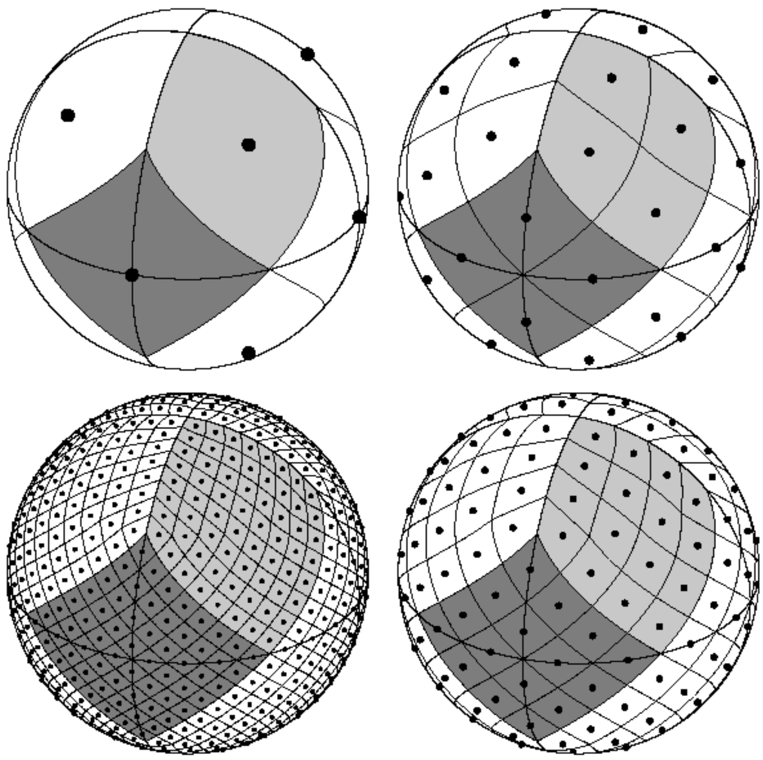

Figure 1: Orthographic view of the Healpix tessellation scheme. The upper left sphere shows the 12 basic elements. Moving clockwise, the other spheres refer to the case in which the sides of those 12 pixel have been divided respectively in 2, 4 and 8 parts to enhance the number of pixels. This figure has been taken from Gorski et al. (2005).

the HEALPIX scheme the number of pixel decreases toward the poles. As a consequence the higher is the latitude of a HEALPIX map element the larger is the number of pixels of the ecp map covering, at least partially, the same sky area. Another important difference is the orientation of the pixels in the two schemes. The pixels of an ecp map have two sides laying along meridians and the others along parallels, whereas the HEALPIX ones appear turned of about 90° respect to this configuration when displayed in a gnomonic view (see Fig. 2).

Consequently there is no 1-1 correspondence between the elements in the two tesselations and a direct transformation from one scheme to the other would mix the values belonging to adjacent pixels of the starting map. The convertion has to be carried out between maps with a number of pixels much larger than the initial, in order to restrict the loss of information (due to the mixing of the original values) to scales $\theta << \theta_{pixel,orig}$. To project the 1420 MHz ecp map into HEALPIX we have implemented a simple algorithm that first regrids the ecp data to a finer step. We verified the reliability of the projection provided by this simple approach, performing successfully a forward and backward transformation between the two pixelization schemes. A sketch of the overall operation is provided in Fig. 3.

The starting point is the ecp map of the 1420 MHz survey, whose $\theta_{pixel} = 15'$. We created a table with as many rows as the number of pixels in the map (1441×721) and three columns referring to the pixel center coordinates and the corresponding intensity value respectively. The ascii file containing the tabulated data constitutes the input of the (IDL) code performing the regridding. The program reads in the coordinates and the value of each pixel, divides it in 225 pixels with $\theta_{pixel} \sim 1'$ and searches the pixel of the Healpix map at $n_{side} = 2048$ in which their center falls. The value attributed to each pixel of the Healpix map is given by the arithmetic average of the values of the associated pixels in the ecp map. To go back we produced again an ascii file, characterized by $N_{pixels,Healpix} = 12 \times n_{side}^2$ rows, each giving the pixel center coordinates and the corresponding value in the Healpix map. A retabulation of the data is necessary also in this case because of the difference in the number of pixels of the two tessellation schemes, that forces to an interpolation over the existing data. The particu-

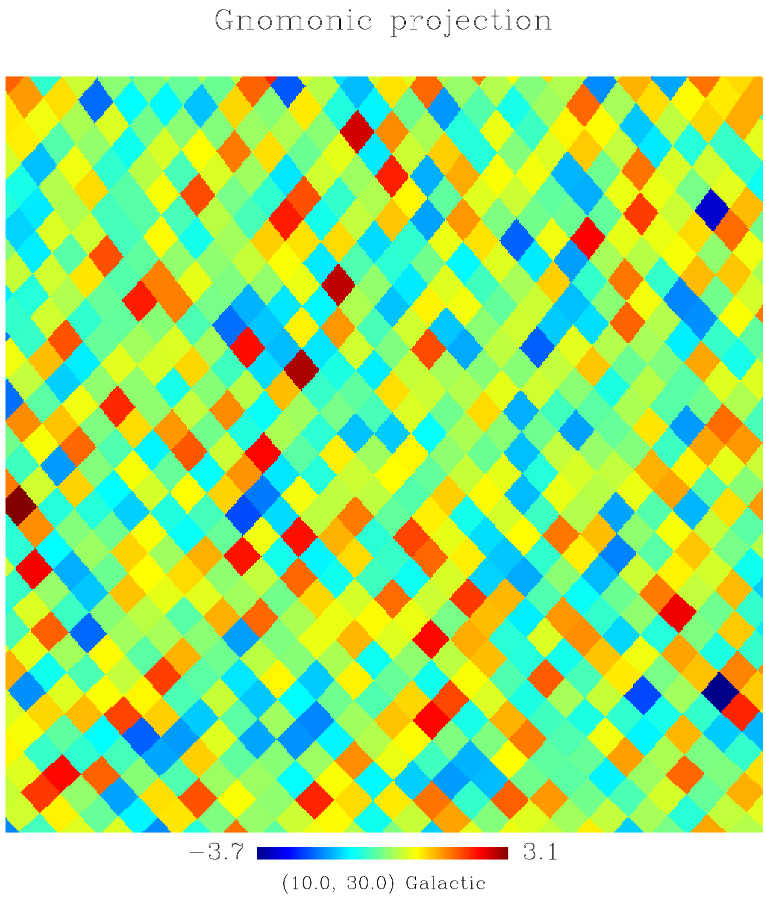

Figure 2: Gnomonic view of a patch extracted from a Healpix map at $n_{side} = 128$. The pixels of the tessellation appear rotated respect to the pixels of an ecp grid.

lar interpolation method of the NOD2-package (routine called ZINTPN) calculates the value to be assigned to an empty pixel performing a polynomial fit over 16 points surrounding it (see Fig. 4 for further details). To provide a continuous solution this procedure requires to avoid strong gradients or dummy values in the data to be interpolated, that can be granted by a much finer regridding. In practice we first transformed the HEALPIX map at $\theta \sim 1.7'$ into an ecp map with the same pixel size and then performed three consecutive regriddings[6] of the latter ($\theta_{pixel} \sim 1.7' \rightarrow 0.5' \rightarrow 1' \rightarrow 2'$) before generating a map with $\theta_{pixel} = 15'$.
We note that the consecutive retabulations enormously enhance the size of the map files, therefore the first ecp map obtained projecting the Healpix tabulated data has preliminarily been divided in 12 submaps. We have separately carried out the three regriddings on each submap and generated 12 submaps with the final pixelsize. Then we have reconstructed the all-sky map by combining these submaps. The whole process requires to allocate a lot of memory and disk space to save the ascii files and the intermediate maps and submaps and needs roughly one day of computing time to accomplish all operations. Namely we used a Linux PC with 2.0 GBytes of RAM to run the regridding algorithm, that (being the PC almost dedicated to our purpose) took about 20 hours computing time. To produce the conversion from Healpix to ecp we used a SUN workstation that has been working almost 6 hours "CPU time" to complete the needed operations.

Comparing the original and the reprojected ecp map we found that the differences are generally zero, except for the areas around the poles, where they can reach values of a few percents because of

[6] These consecutive regriddings have been realized making a special use of the ZINTPN procedure. We allowed the interpolation to take place even when the suitable - not containing dummies - points were much less than 16.

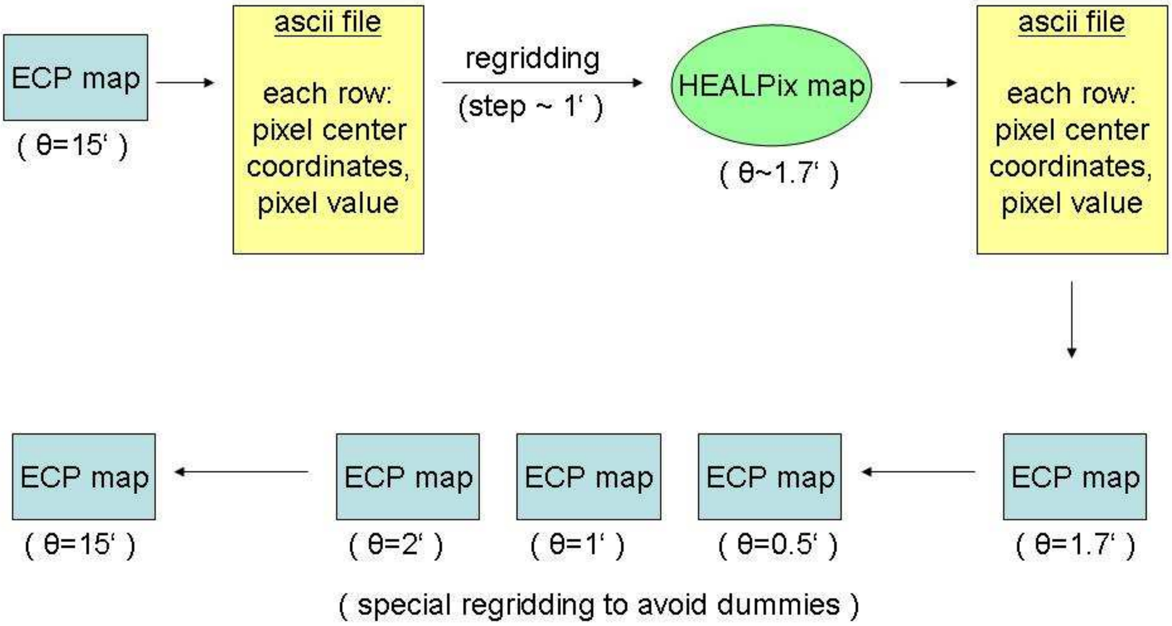

Figure 3: Sketch of the overall projection process.

the large discrepancy in the number of pixels available in the two partition schemes. From our positive results one can infer that the transformation of ecp maps into HEALPIX maps is safely achieved at least in case the following conditions are fullfilled: 1) the ecp data are regridded adopting a step of about one fifteenth of the original pixel size or smaller, i.e. $\theta_{ecp} \lesssim 1/15 \times \theta_{ecp,orig}$; 2) $\theta_{Healpix} \sim 2 \times \theta_{ecp}$.

The HEALPIX map we produced at 1420 MHz does not contain statistical informations on scales smaller than the corresponding θ_{HPBW}, therefore it has been degraded to a map with smaller pixel size. Comparing the angular power spectra of the HEALPIX map at $n_{side} = 2048$ with the angular power spectra of a degraded version, we found that they almost coincide up to $\ell \sim 350$ ($\ell \sim 180°/\theta$) for $n_{side} \gtrsim 512$. Being limited in our analysis by the survey's angular resolution to $\ell \lesssim 300$ we decided to deal with the HEALPIX map at this n_{side}.

The implemented algorithm has been also applied to produce a HEALPIX version of the 408 MHz total intensity map (Haslam et al. 1982) and of the DRAO 1420 MHz polarization survey, covering the northern celestial hemisphere (Wolleben et al. 2005). In Fig. 5 we show all the produced Healpix maps.

References

[1] Haslam, C. G. T. 1974, A&AS,15,333

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[3] Gorski, K. M., Hivon, E., Banday, A. J., Wandelt, B. D., Hansen, F. K., Reinecke, M., & Bartelmann, M. 2005, ApJ, 622, 759

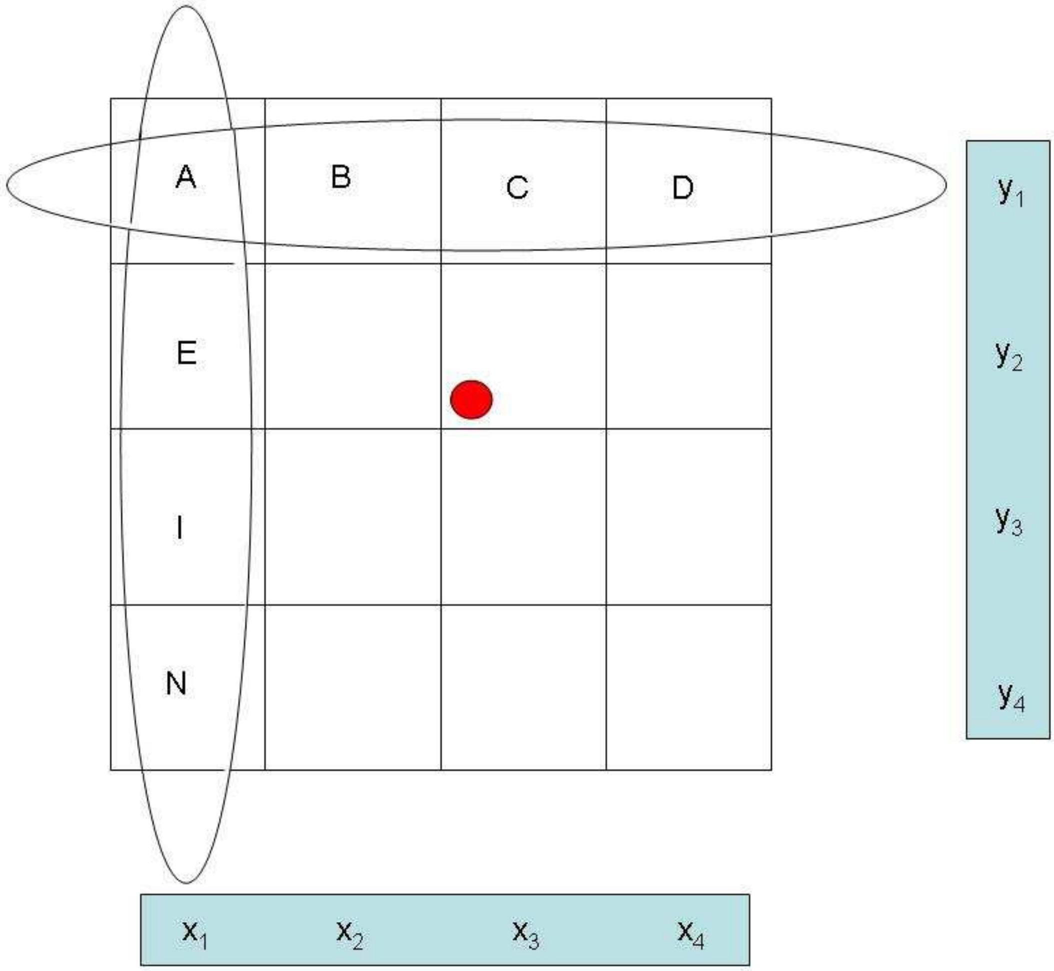

Figure 4: Sketch of the interpolation scheme. The point indicates the position to be retabulated and the 16 points surrounding it in the original grid. The ZINTPN code divides these 16 points in 4 groups of 4 elements each. One can choose whether to consider 4 groups of isolatitude pixels or 4 of isolongitude pixels. For each group it interpolates separately the three pixels on the left and the three on the right of the position to be filled, exploiting 2-order polynomial functions. Then it calculates the value (either x_i or y_i) to be assigned to the group as the some particular weighted average of the two. The same algorithm is then applied to the 4 new values to give the final result of the interpolation.

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[6] Reich, P., Testori, J. C., & Reich, W. 2001, A&A,376,861

[7] Wolleben, M., Landecker, T. L., Reich, W., & Wielebinski, R. 2005, A&A, in press, astro-ph/0510456

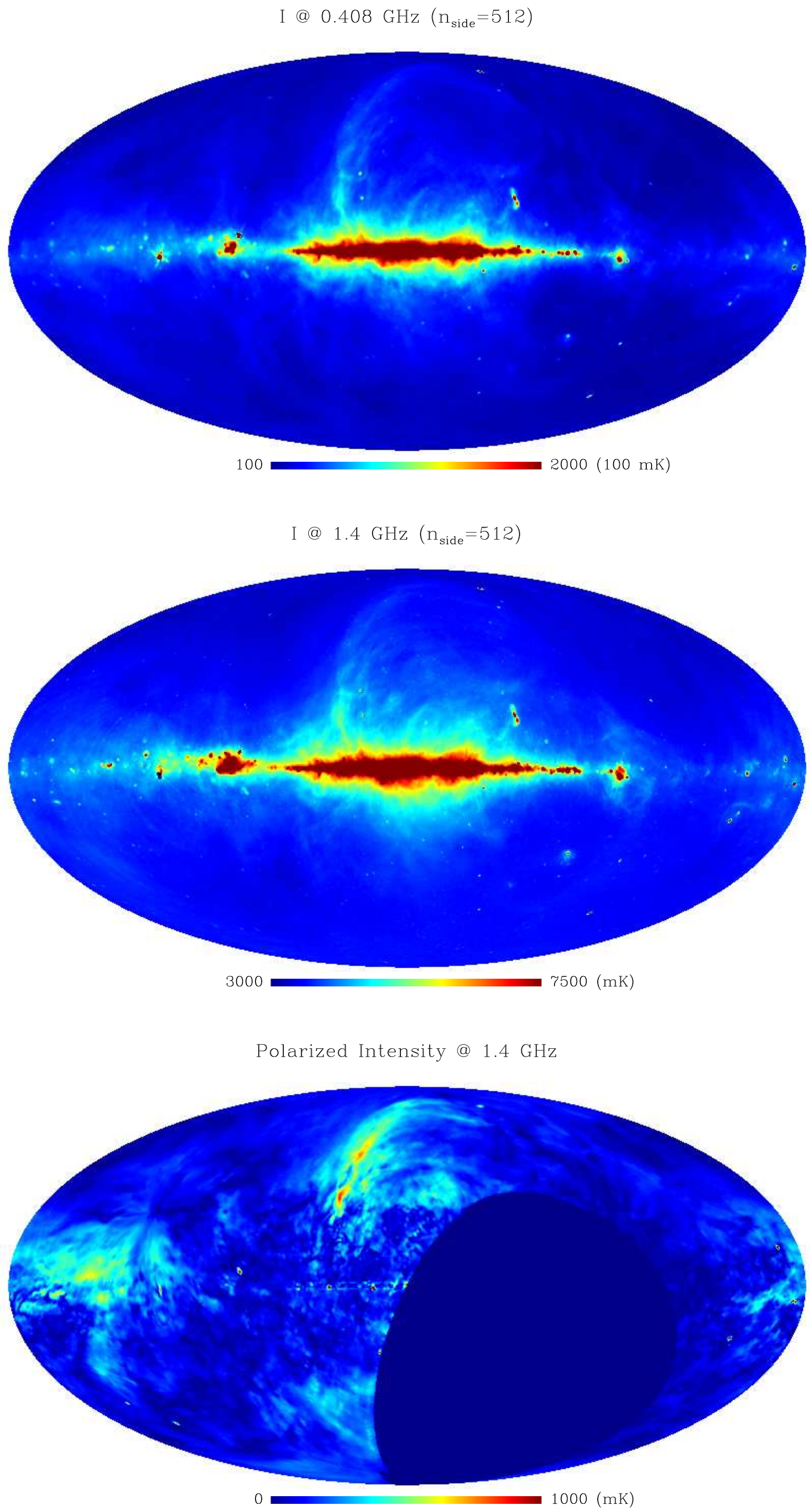

Figure 5: Maps projected into HEALPix tessellation scheme exploiting the regridding algorithm. From the top: total intensity map at 408 MHz (Haslam et al. 1982), total intensity map at 1420 MHz (Reich 1982 ; Reich & Reich 1986; Reich et al. 2001) and DRAO polarized intensity map at 1420 MHz (Wolleben et al. 2005).