GALACTIC COORDINATE SYSTEM BASED ON MULTI-WAVELENGTH CATALOGUES

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ABSTRACT. The currently used Galactic Coordinate System (GalCS) is based on the FK5 system at J2000.0, which was transformed from the FK4 system at B1950.0. The limitations and misunderstandings for this transformed GalCS is necessarily be avoided by defining a new GalCS connecting directly to the International Celestial Reference System (ICRS). We try to find the best orientation of the GalCS using data from two all-sky surveys: AKARI and WISE at six wavelengths between 3.4 μm to 90 μm, and synthesize results obtained at various wavelengths to define an improved GalCS in the framework of the ICRS. The revised GalCS parameters for defining the new GalCS in the ICRS are summarized as: $\alpha^{\rm p} = 192\overset{\circ}{.}777$, $\delta^{\rm p} = 26\overset{\circ}{.}9298$, for the equatorial coordinates of the north Galactic pole and $\theta = 122\overset{\circ}{.}95017$ for the position angle of the Galactic center. As one of the Galactic sub-structures, the Galactic warp presents different forms in different GalCS that are constructed with various data and methods, which shows the importance of re-defining a Galactic coordinate system by the IAU for better study of the Galactic structure and kinematics.

1. INTRODUCTION

The Galactic coordinate system (hereafter GalCS) is a practical coordinate system for studies of the Galactic structure, kinematics, and dynamics. The current GalCS adopted by the Hipparcos team is related to the J2000.0 FK5-based reference system (Murray 1989) which was transformed from its original IAU 1958 definition based on the FK4 reference system (Blaauw et al. 1960). Liu et al. (2011a) found that this transformed coordinate system is not an optimal one and it can also lead to misunderstandings. So a new GalCS directly related to the International Celestial Reference System (ICRS) is necessary. More recently, by adopting all-sky survey data from 2MASS in near-infrared band and SPECFIND v2.0 in radio band, Liu et al. (2011b, hereafter L11b) have updated the three parameters used to define the directions of axes of the GalCS in the equatorial system, namely $\alpha^{\rm p}$, $\delta^{\rm p}$, and θ, where ($\alpha^{\rm p}$, $\delta^{\rm p}$) is the equatorial coordinate of the north Galactic pole (NGP) and θ is the position angle of the Galactic center (GC). We note that there remains room for improvement in establishing a more proper GalCS. In this work, we use catalogues from latest all-sky surveys to revise the GalCS parameters.

2. DATA

As described in L11b, a well-defined GalCS should coincide with the feature of the Milky Way. An optimal GalCS means that the distribution of the Galactic sources on the celestial sphere is symmetric about the basic plane (i.e. $x - y$ plane) of the GalCS. It should be noted that the interstellar extinction prevents us to obtain a complete distribution of stars in the optical band. Thus large infrared catalogues are the most suitable data to find the position of the basic plane because the effect of extinction in long band is relatively weak. In this work, we use catalogues from the AKARI infrared all-sky survey (Murakami et al. 2007) and catalogues from Wide-field Infrared Survey Explorer (WISE) (Wright et al. 2010) to carry out following computations.

The AKARI survey provided catalogues in two bands centered at 9 μm and 90 μm respectively. We need to reject sources near the Sun by removing sources with high fluxes and abandon extragalactic sources with low fluxes or staying away from the Milky Way belt (e.g. the Large and Small Magellanic Cloud). Therefore we only selected sources between $\pm 15^\circ$ of latitude in the flux range from 0.101 Jy to 45 Jy in 9 μm band and sources within $\pm 6^\circ$ of latitude with fluxes between 0.46 Jy and 120 Jy in 90 μm band. Figure 1 shows the distribution of selected sources observed at the two bands respectively. We can see clearly the Milky Way belt on the celestial sphere.

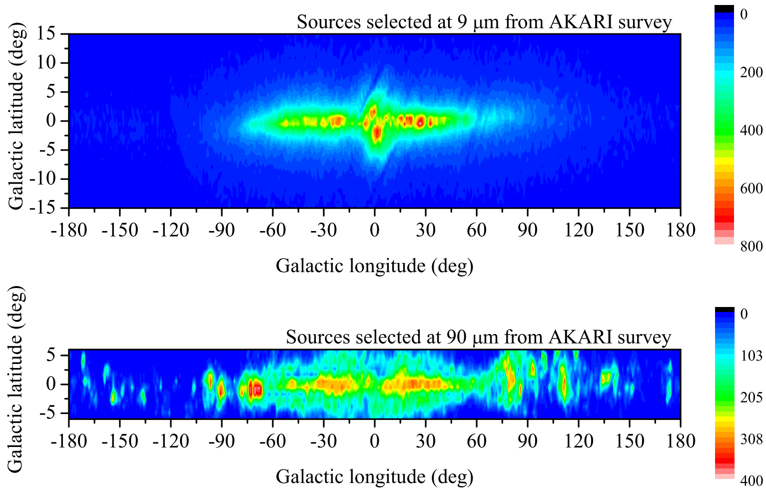

Figure 1: The distribution of sources selected from 9 μm and 90 μm observations of AKARI, respectively.

The WISE all-sky catalog contains positions and four-band (centered at 3.4 μm, 4.6 μm, 12 μm, 22 μm respectively) information of photometry. Like what we have done for AKARI data, we determine the magnitude ranges of selected WISE sources, which are such that $10 < m_{3.4\mu\mathrm{m}} < 14.8$, $9 < m_{4.6\mu\mathrm{m}} < 14.5$, $8.5 < m_{12\mu\mathrm{m}} < 12.4$, $5.5 < m_{22\mu\mathrm{m}} < 8.8$. We retain the data with $|b| < 25°$ in 3.4 μm band, $|b| < 20°$ in 4.6 μm band, $|b| < 4°$ in 12 μm band and $|b| < 3°$ in 22 μm band. For 12 μm and 22 μm bands, the selected sources are restricted within the longitude range from $-60°$ to $60°$.

3. CALCULATING GALCS PARAMETERS WITH DIFFERENT METHODS

Our purpose is to calculate the three parameters $(\alpha^{\mathrm{p}}, \delta^{\mathrm{p}}, \theta)$ for the GalCS orientation in the equatorial coordinate system. We can obtain the direction of NGP, the z-axis, by fitting the equation for the position of the basic plane of GalCS, to the distribution of chosen data. We can also adopt the direction of GC, i.e. the direction of the x-axis of the GalCS, using results from direct observations for the Sgr A*. To keep the orthogonality of the GalCS, we used two methods to find the orientation of the GalCS. The first method is to fix the z-axis of the GalCS from the LSQ method, and then to find the direction of the x-axis by adopting the position of Sgr A* at the GC (hereafter the z-fixed method). The second method, called x-fixed method is to fix the direction of the x-axis to the observed position of Sgr A* and then to determine the direction of the z-axis perpendicular to the x-axis with the survey data.

In the z-fixed method, we first fit the position of NGP. Figure 2 presents values for α^{p} and δ^{p} in six bands, associated with the results from the 2MASS (1.25 μm band) and the SPECFIND v2.0 catalogues (radio band) as provided by L11b. The differences between the values for both α^{p} and δ^{p} derived from different bands are at an order of 0.1°.

After calculating the mean values of α^{p} and δ^{p}, we obtain the position angle θ of GC (Sgr A*). The position of Sgr A* can be found in Reid & Brunthaler (2004). The new parameters based on the z-fixed method that define the orientation of the new GalCS in the ICRS are such that

$$\begin{aligned} \alpha^{\mathrm{p}}_{\mathrm{z-fixed}} &= 192\overset{\circ}{.}582, \\ \delta^{\mathrm{p}}_{\mathrm{z-fixed}} &= 26\overset{\circ}{.}8935, \\ \theta_{\mathrm{z-fixed}} &= 122\overset{\circ}{.}86216. \end{aligned} \quad (1)$$

In the x-fixed method, we fit the position angle η of the NGP (see Fig. 5 of L11b) to find an optimal z-axis. We obtained the best results for η for six wavelengths as shown in Fig. 3, associated with the values from 2MASS and SPECFIND provided by L11b.

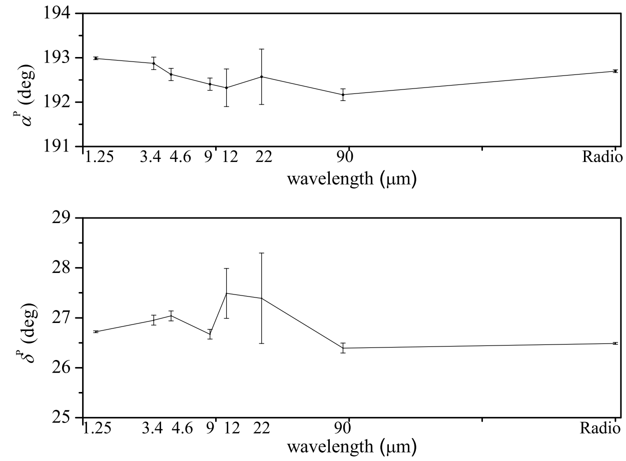

Figure 2: The values of α^{p} and δ^{p} fitted at different wavelengths with the z-fixed method.

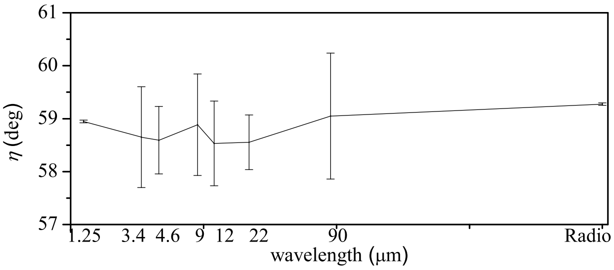

Figure 3: Values of η fitted in different bands with the x-fixed method.

We apply the mean value of η and the position of Sgr A* to obtain the revised values for GalCS parameters:

$$
\begin{aligned}
\alpha^{\mathrm{p}}_{\mathrm{x-fixed}} &= 192^{\circ}\!.777, \\
\delta^{\mathrm{p}}_{\mathrm{x-fixed}} &= 26^{\circ}\!.9298, \\
\theta_{\mathrm{x-fixed}} &= 122^{\circ}\!.95017.
\end{aligned} \tag{2}
$$

4. THE GALACTIC WARP IN DIFFERENT GALCS

The study of the typical form of the Galactic warp, a famous Galactic sub-structure, is closely related to the GalCS. We can analyze the effect of different GalCS on the study of the structure of the Milky Way by comparing the fitted warp parameters, the inclination angle b_{w} of the warp plane with respect to the Galactic plane and the Galactic longitude l_{w} of the intersecting line of two planes.

The data used to fit the warp plane is selected from Hipparcos O-B5 stars (Miyamoto & Zhu 1998). The results (in the GalCS derived from the x-fixed method) are shown in Fig. 4. (The GalCS related to 2MASS and SPECFIND are from L11b.) Both b_{w} and l_{w} change evidently with the Galactic wavelengths. This shows that an explicit and unitive definition of the GalCS is important for study the Galactic structures.

5. RECOMMENDATION ON THE NEW GALCS

The GalCS parameters derived from the z-fixed and x-fixed methods differ in an order of 0.1°. By comparing the two methods, we recommend results derived from the x-fixed method to be the new GalCS parameters, taking consideration of its lower uncertainty. The inclination of the revised basic plane with

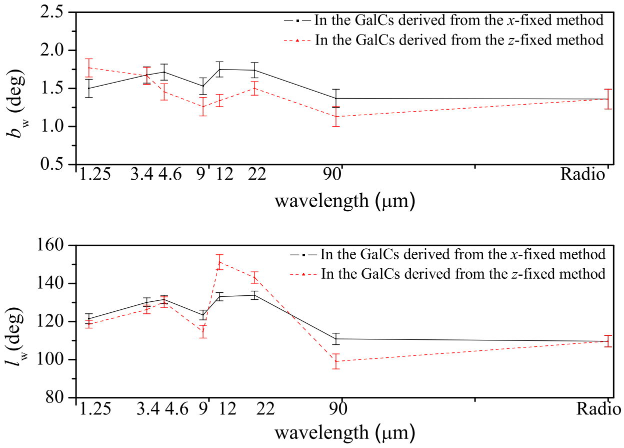

Figure 4: The warp parameters fitted in the GalCS in eight bands. Results in the GalCS derived from the x-fixed and z-fixed methods in each band are provided for comparison.

respect to the original basic plane is 0.2°. The numerical transformation matrix $\mathcal{N}$ from the equatorial to the Galactic coordinate system can be written as:

$$\mathcal{N} = \begin{pmatrix} -0.0546533401 & -0.8728440988 & -0.4849290583 \\ +0.4909257965 & -0.4463911532 & +0.7481489161 \\ -0.8694854080 & -0.1971753470 & +0.4528984519 \end{pmatrix}. \quad (3)$$

Though there exist several uncertainties, the newly established GalCS is closer to the feature of the Milky Way than the traditional one. The transformation definition based on IAU 1958 GalCS should be dropped and the new definition of the GalCS based on modern observations is possible.

6. REFERENCES

Blaauw, A., Gum, C.S., Pawsey, J.L., Westerhout, G., 1960, “The new I. A. U. system of galactic coordinates (1958 revision)”, MNRAS, 121, 123.

Liu, J.-C., Zhu, Z., Zhang, H., 2011a, “Reconsidering the Galactic coordinate system”, A&A, 526, A16.

Liu, J.-C., Zhu, Z., Hu, B., 2011b, “Constructing a Galactic coordinate system based on near-infrared and radio catalogs”, A&A, 536, A102.

Miyamoto, M., Zhu, Z., 1998, “Galactic Interior Motions Derived from HIPPARCOS Proper Motions. I. Young Disk Population”, AJ, 115, 1483.

Murakami, H., Baba, H., Barthel, P., et al., 2007, “The Infrared Astronomical Mission AKARI”, PASJ, 59, 369.

Murray, C.A., 1989, “The transformation of coordinates between the systems of B1950.0 and J2000.0, and the principal galactic axes referred to J2000.0”, A&A, 218, 325

Reid, M.J., Brunthaler, A., 2004, “The Proper Motion of Sagittarius A*. II. The Mass of Sagittarius A*”, ApJ, 616, 872.

Wright, E.L., Eisenhardt, P.R.M., Mainzer, A.K., et al., 2010, “The Wide-field Infrared Survey Explorer (WISE): Mission Description and Initial On-orbit Performance”, AJ, 140, 1868.